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FINAL REPORT FOR RESEARCH AGREEMENT
#INT-94895-RJVA
"Correlating Weather with Survival and Maturity of Western Larch Cones"
MONTANA STATE UNIVERSITY
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THESIS/
REPORTS

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P.E.

CORRELATING WEATHER WITH SURVIVAL AND MATURITY OF WESTERN LARCH CONES

FINAL REPORT
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CORRELATING WEATHER WITH SURVIVAL AND MATURITY OF WESTERN LARCH CONES

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Between

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INTRODUCTION

Cones and seeds of western larch *(Larix occidentalis)* originating after wild fires earlier this century was monitored from four to ten years at fourteen sites ranging from 762 m to 1,768 m. The purpose was to identify major factors decreasing cone and seed potential within the natural range of larch in the United States. Nine study areas were in Idaho, two in Montana, two in Oregon, and one in Washington (Fig. 1). Air temperature was monitored at 13 study sites (Savage Camp in north Idaho was not instrumented). Access and failure of equipment precluded a complete data record. Accessibility of some sites and scope of the project limited the number of visits. Temperatures from nearby National Weather Service Climatological Stations were correlated to temperatures at study sites and were used to estimate missing temperature data. Growing degree-days at 2°C and 5°C thresholds were calculated from the completed temperature records. Daily minimum temperatures below -3°C were noted in the spring season after mean daily temperatures exceeded the 5°C threshold and were compared to the estimated phenological stage based on accumulated degree-days. Minimum temperatures, phenological stage, and cone survival were compared and minimum daily temperatures that might inhibit cone or seed development for that season were identified and summarized.

Study Sites

Location, elevation, and average tree age are tabulated in Table 1. Data collection began at eight sites in 1985, expanded to eleven sites in 1986, fourteen in 1987; then dropped to seven in 1990 and four from 1992 through 1994 (Table 2). Four sites had records for all 10 years with records at other study sites varying from 4 to 5 years (Table 2). No temperature data was collected at the Savage Camp site in Idaho. Ten sample trees were used to observe and collect seed cones at each location with only five trees used at Savage Camp. Air temperatures were obtained using an Omnidata "Easy Logger" field unit that was installed in close proximity to the sample trees. A detailed description of sampling methods is discussed in Jenkins and Shearer (1988).

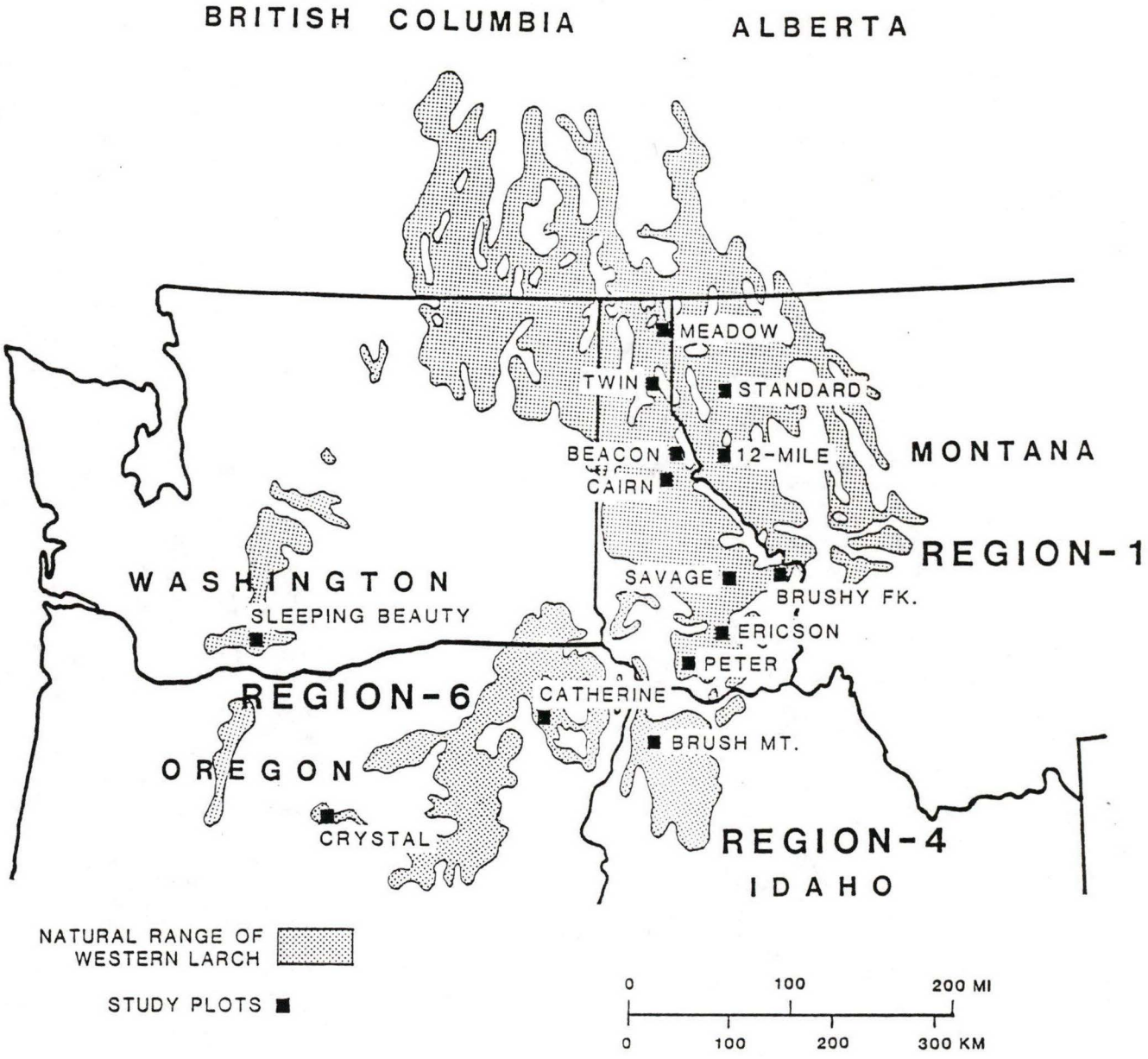

Figure 1.--Distribution of 14 study areas within the natural range of western larch.

Table 1. Location, elevation, and average tree age of western larch study sites in Idaho, Montana, Oregon, and Washington.

Site Number	Study Area	Latitude	Longitude	Elevation (m)	Average tree age (years[1])
		Idaho			
3	Beacon Light	48°04'	115°31'	1,097	83
7	Brush Mountain	45°09'	116°22'	1,524	63
10	Brushy Fork	46°38'	114°28'	1,463	75
11	Cairn Creek	47°22'	115°32'	1,463	63
5	Ericson Ridge	45°54'	115°29'	1,433	55
1	Meadow Creek	48°46'	116°14'	762	80
6	Peter Ready Creek	45°39'	116°03'	1,768	64
4	Savage Camp	46°29'	115°32'	1,463	46
2	Twin Creeks	48°04'	116°09'	853	82
		Montana			
9	Standard Creek	48°04'	115°31'	1,097	68
8	Twelvemile Creek	47°28'	115°17'	1,372	65
		Oregon			
14	Catherine Summit	45°06'	117°40'	1,249	52
12	Crystal Springs	44°28'	120°23'	1,463	98
		Washington			
13	Sleeping Beauty	46°04'	121°35'	807	71

[1]Age determined the year of installation.

Table 2. Years with seed cone(C)and temperature (T) data for western larch study sites in Idaho, Montana, Oregon, and Washington.

Site Number	Study Site	1985		1986		1987		1988		1989		1990		1991		1992		1993		1994	
		C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T
	Idaho																				
3	Beacon Light	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
7	Brush Mountain	X	X	X	X	X	X	X	X	X	X										
10	Brushy Fork			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
11	Cairn Creek			X	X	X	X	X	X	X	X										
5	Ericson Ridge	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	P
1	Meadow Creek	X	X	X	X	X	X	X	X	X	X										
6	Peter Ready Creek	X	X	X	X	X	X	X	X	X	X										
4	Savage Camp	X		X		X		X		X											
2	Twin Creeks	X	X	X	X	X	X	X	X	X	X										
	Montana																				
9	Standard Creek	X	X	X	X	X	X	X	X	X	X										
8	Twelvemile Creek	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Oregon																				
14	Catherine Summit					X		X	X	X	X	X	X	X	X						
12	Crystal Springs					X	X	X	X	X	X	X	X	X	X						
	Washington																				
13	Sleeping Beauty					X	X	X	X	X	X	X	X	X							

P = Partial Record

Estimating Missing Temperature Data

Daily maximum, minimum and mean of hourly air temperature observations to the nearest tenth of °F were provided from on-site recorders. Missing data was estimated from the nearest National Weather Service (NWS) climatological station. Mean monthly maximums and mean monthly minimums were compared for periods where both the on-site recorders and NWS stations had complete records. This relationship was used to estimate missing daily data at 13 study sites (Table 3). If two or more NWS sites were in the area, the stations with the best correlation were used. The original temperature data collected at the study sites was reported in tenths of °F. By tabulating the estimates of missing temperatures to the nearest whole °F, estimated data would be identified (nearest whole °F) without flagging.

Once the temperature data files were complete, all values were converted to the nearest one-tenth °C. Mean daily temperatures were computed by averaging the daily maximum and minimum temperatures. This method of determining mean daily temperature and degree-days is compatible with NWS climatological station data where only maximum and minimum temperatures are observed. It also allows comparisons with Natural Resource Conservation Service (NRCS) SNOTEL (Snow Survey Telemetry) sites where maximum and minimum temperature values are recorded. By calculating mean daily temperatures as the average of maximum and minimum, data can be extrapolated to any location having temperature observations.

Degree Days

It is generally recognized that western larch is one of the earlier species to break bud dormancy. Worrall (1993) suggested that subalpine larch breaks dormancy when mean daily temperature is above 1.5°C. In this study, the degree-days were calculated for both 2°C temperature threshold and the more commonly used temperature threshold of 5°C (mean daily temperature) to indicate the breaking of dormancy. The mean daily temperature is calculated as the average of the daily maximum and the daily minimum temperature. The starting day for accumulating degree-days was the first day where mean daily temperatures exceeded the threshold values. Only positive values are accumulated for degree-day totals. Because we recognized that one day when the mean exceeded the threshold early in the spring may not necessarily indicate a break in dormancy, the starting date and accumulated degree-days after three consecutive days with mean daily temperatures above the threshold were also identified. This method was used by Hannerz (1994) on first occurrences of bud burst in Norway spruce. Tables 4 through 16 summarize the dates of when the temperatures exceeded the threshold and the accumulated degree-days for the thirteen study areas (no temperature records were available for Savage Camp). Figures 2 through 14 show the average degree-day accumulations graphically.

Daily temperatures and accumulated degree-days for all study sites are available from the Forestry Sciences Laboratory, 800 East Beckwith Avenue, Box 8089, Missoula, MT 59807-8089.

Table 3. Equations developed to estimate missing temperatures at study sites.

Study Site	Equations (All temperatures in °F)[1]
Idaho	
Beacon Light	Mullan Tmin - 1°F
	Mullan Tmax - 4°F (over 70°)
	Mullan Tmax - 5°F (less 40°)
	Mullan Tmax - 6°F (between 40° and 70°)
Brush Meadows	McCall Tmin + 6°F
	McCall Tmax - 2°F
Brushy Fork	Powell Tmin - 2°F
	Powell Tmax - 5°F
Cairn Creek	1.2 x Mullan Tmin - 5°F
	Mullan Tmax - 5°F
Ericson Ridge	Elk City Tmin + 6°F
	Elk City Tmax - 5°F (above 50°)
	Elk City Tmax - 3°F (below 50°)
Meadow Creek	Bonners Ferry Tmin - 2°F
	Bonners Ferry Tmax - 5°F (above 40°)
	Bonners Ferry Tmax - 4°F (below 40°)
Peter Ready Creek	Grangeville Tmin + 2 (between 45° and 50°)
	Grangeville Tmin + 1 (between 40° and 45°)
	Grangeville Tmin 0 (between 35° and 40°)
	Grangeville Tmin - 1 (between 30° and 35°)
	Grangeville Tmin - 2 (between 25° and 30°)
	Grangeville Tmin -3 (between 20° and 25°)
	Grangeville Tmin - 4 (between 15° and 20°)
	Grangeville Tmin - 5 (less than 15°)
	Grangeville Tmax - 10 (above 40°)
	Grangeville Tmax - 7 (below 40°)
Twin Creek	Cabinet Gorge Tmin (above 20°)
	Cabinet Gorge Tmin - 1°F (below 20°)
	Cabinet Gorge Tmax - 4°F (above 60°)
	Cabinet Gorge Tmax - 3°F (below 60°)
Montana	
Standard Creek	Libby 32SSE Tmin + 4°F
	Libby 32SSE Tmax + 1°F
Twelvemile Creek	Libby 32SSE Tmin + 4°F
	Libby 32SSE Tmax - 4°F
Oregon	
Catherine Summit	Baker AP Tmin + 2°F
	Baker AP Tmax - 6°F
Crystal Springs	Mitchell 17SW Tmin - 2°F
	.84 x Mitchell 17SW Tmax + 8°F
Washington	
Sleeping Beauty	Mt. Adams RS Tmin -4°F
	Mt. Adams RS Tmax -1°F

[1] Stations are all NWS climatological stations.

Table 4. Accumulated heating degree-days above 5°C and 2°C mean daily temperatures, Beacon Light study area, Idaho.[1]

Year	First day over 5°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (5°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1985	4/08	9	4/10	0	40	187	425	901	1179	1258
1986	3/06	5	3/29	0	26	208	526	796	1239	1342
1987	3/05	6	4/02	0	88	263	574	880	1199	1472
1988	2/28	14	4/12	0	51	179	454	808	1172	1381
1989	3/10	10	4/14	0	30	134	400	799	1092	1298
1990	3/19	8	4/01	0	35	104	328	709	1064	1396
1991	1/12	9	2/03	22	36	125	283	649	1043	1283
1992	1/30	11	2/01	78	137	345	650	973	1307	1457
1993	3/22	7	4/18	0	4	224	409	598	877	1063
1994	3/01	22	4/17	0	27	190	410	828	1232	1489
Aug	3/02	10	3/27	10	47	196	446	794	1140	1344
Year	First day over 2°C	Accum ° Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (2°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1985	3/16	3	3/18	6	115	343	671	1240	1611	1770
1986	1/10	8	3/01	23	92	350	758	1120	1656	1849
1987	3/03	8	3/05	18	174	440	841	1240	1652	2015
1988	1/28	12	2/28	18	137	348	712	1160	1600	1915
1989	1/29	10	3/10	7	116	304	659	1152	1537	1833
1990	2/25	13	3/19	25	127	270	556	1057	1505	1927
1991	1/11	10	1/13	128	187	360	607	1067	1554	1881
1992	1/24	5	1/26	232	348	647	1041	1457	1881	2116
1993	3/06	18	3/27	8	74	384	658	940	1312	1584
1994	2/16	10	3/03	27	125	380	691	1201	1684	2047
Aug	2/10	10	3/01	49	150	383	719	1163	1599	1894

[1] Mean daily temperature based on average of daily maximum and minimum temperatures.
[2] Accumulated degree-days starting after 3rd consecutive day above 5°C and 2°C.
[3] Degree-days accumulated between first day above 5°C and 2°C and third consecutive day with mean daily temperature above 5°C and 2°C.
[4] Date of third consecutive day having mean daily temperature above 5°C and 2°C.

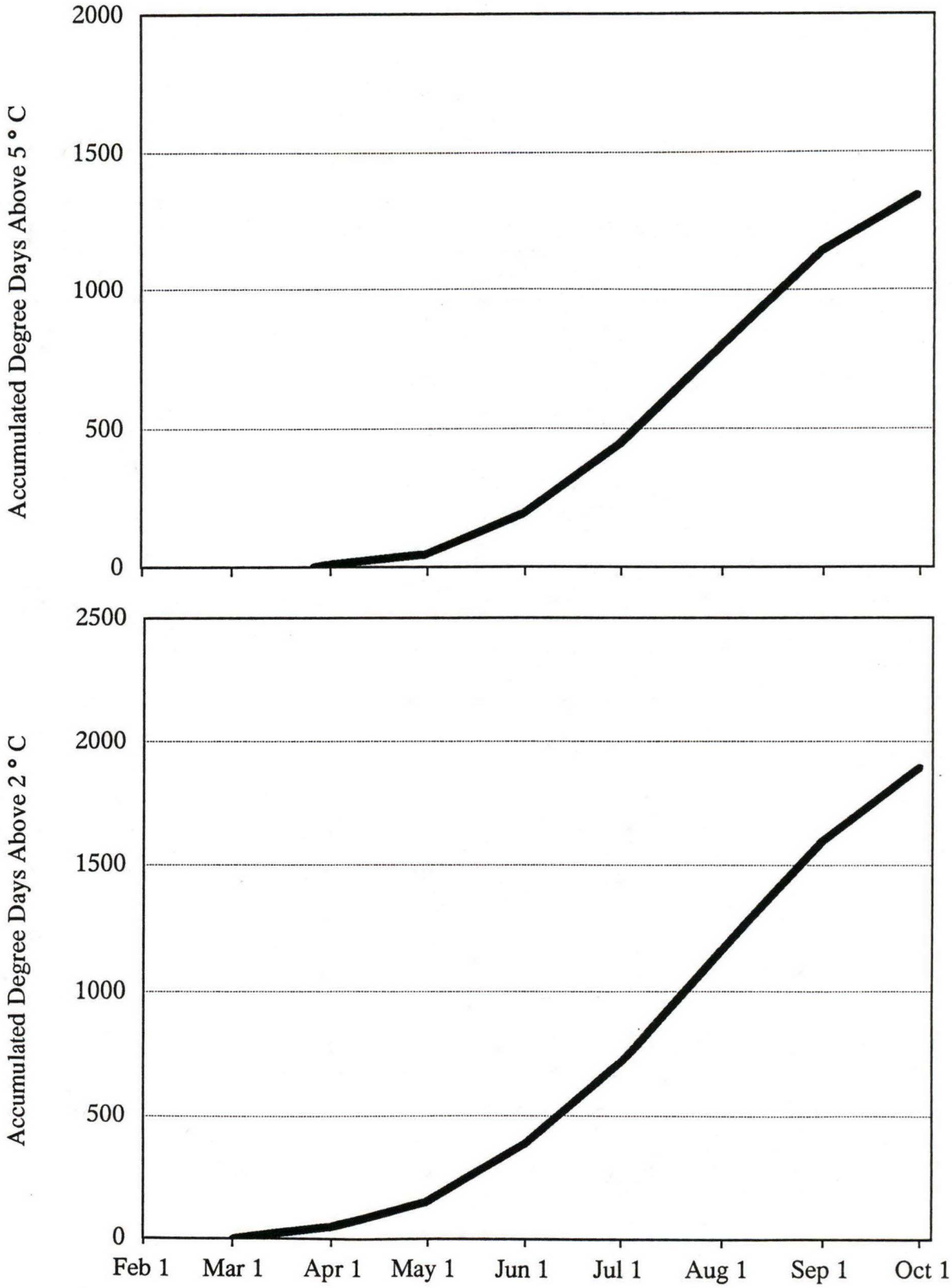

Figure 2. Average accumulated heating degree days above 5° C and 2° C mean daily temperatures starting after the third consecutive day above 5° C and 2° C. Beacon Light study area, Idaho.

Table 5. Accumulated heating degree-days above 5°C and 2°C mean daily temperatures, Brush Mountain study area, Idaho.[1]

Year	First day over 5°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (5°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1985	4/01	5	4/03	0	81	271	571	1035	1343	1439
1986	2/24	8	3/02	14	51	249	572	950	1299	1390
1987	3/04	15	4/02	0	126	334	644	983	1349	1653
1988	2/26	3	2/28	7	88	237	550	962	1332	1534
1989	3/10	9	4/07	0	50	153	426	850	1163	1359
Aug	3/08	8	3/21	4	79	249	553	956	1297	1475
Year	First day over 2°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (2°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1985	3/17	4	3/19	10	165	447	837	1394	1795	1975
1986	1/19	13	2/26	67	153	436	849	1320	1762	1929
1987	1/27	14	3/04	30	234	534	934	1367	1826	2219
1988	2/12	10	2/26	40	182	416	818	1324	1787	2077
1989	2/24	14	3/11	3	127	316	679	1196	1602	1888
Aug	2/11	11	3/06	30	172	430	823	1320	1754	2018

Mean daily temperature based on average of daily maximum and minimum temperatures.
Accumulated degree-days starting after third consecutive day above 5°C or 2°C.
Degree-days accumulated between first day above 5°C or 2°C and third consecutive day with mean daily temperatures above 5°C or 2°C.
Date of third consecutive day having mean daily temperatures above 5°C or 2°C.

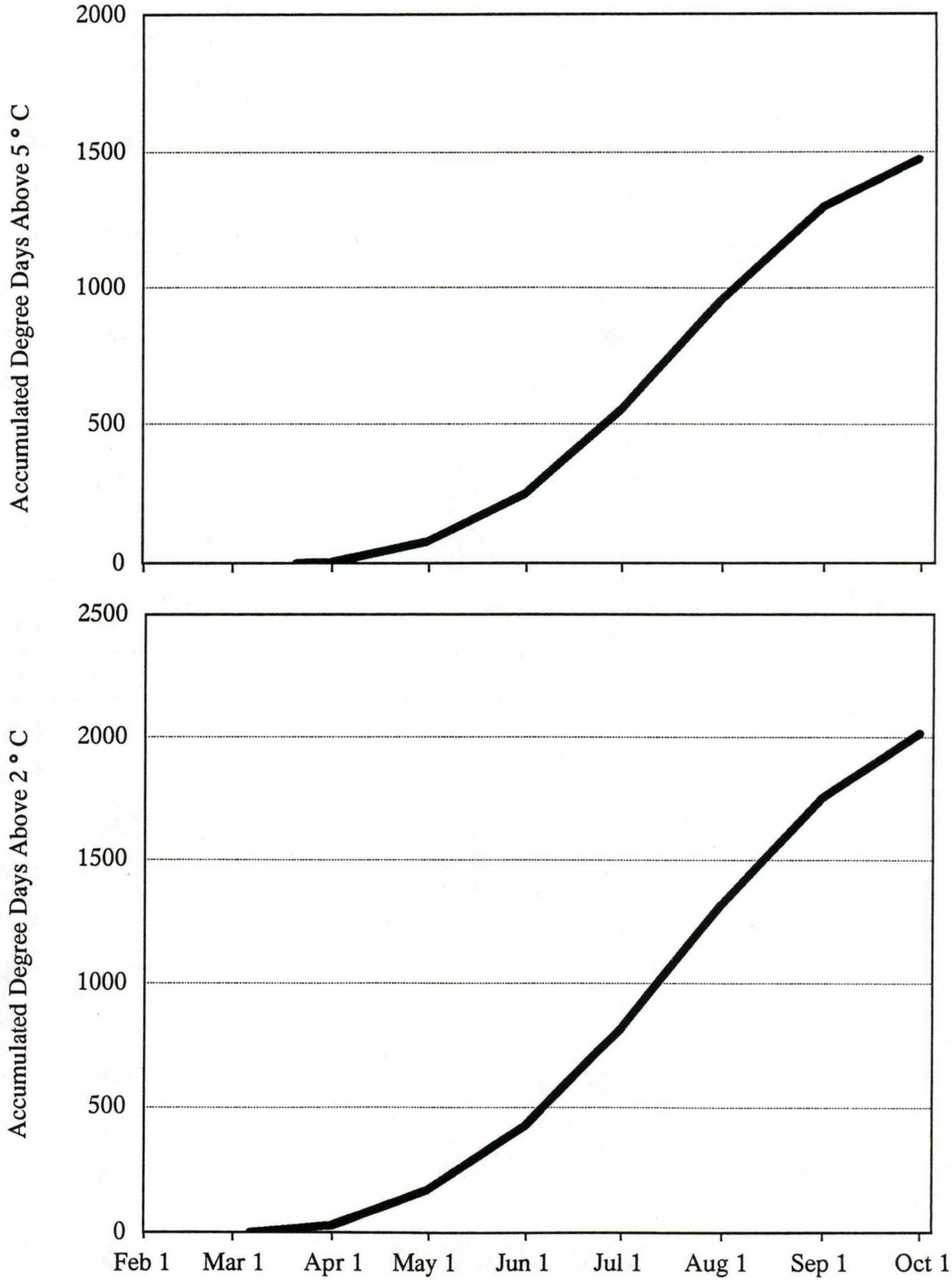

Figure 3. Average accumulated heating degree days above 5° C and 2° C mean daily temperatures starting after the third consecutive day above 5° C and 2° C. Brush Mountain study area, Idaho.

Table 6. Accumulated heating degree-days above 5°C and 2°C mean daily temperatures, Brushy Fork study area, Idaho.[1]

Year	First day over 5°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (5°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1986	3/21	5	3/30	0	21	177	487	732	1081	1156
1987	3/04	6	4/04	0	70	225	496	780	1032	1230
1988	4/06	14	4/13	0	30	140	439	767	1070	1216
1989	3/11	8	4/15	0	17	92	308	708	967	1102
1990	3/18	9	4/02	0	33	86	275	599	898	1137
1991	4/01	4	4/22	0	2	68	207	540	890	1067
1992	3/14	4	4/01	0	37	194	446	714	993	1128
1993	4/08	3	5/03	0	0	167	314	490	712	836
1994	3/15	14	4/18	0	17	139	319	665	984	1181
Aug	3/21	7	4/12	0	25	143	366	666	959	1117
Year	First day over 2°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (2°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1986	2/25	6	3/03	23	88	313	713	1051	1493	1652
1987	3/04	9	3/06	6	145	386	747	1124	1469	1755
1988	2/28	11	3/21	2	98	282	671	1092	1488	1719
1989	1/30	6	3/11	6	85	240	545	1038	1389	1622
1990	1/09	13	3/19	15	118	238	516	933	1325	1654
1991	2/04	9	4/02	0	29	168	397	824	1266	1532
1992	1/31	4	2/28	44	129	375	717	1078	1446	1643
1993	3/06	9	3/24	8	37	291	520	790	1105	1309
1994	3/01	5	3/03	16	92	307	574	1013	1432	1712
Aug	2/11	8	3/13	13	91	289	600	994	1379	1622

[1]Mean daily temperatures based on average of daily maximum and minimum temperatures.
[2]Accumulated degree-days starting after third consecutive day above 5°C and 2°C.
[3]Degree-days accumulated between first day above 5°C or 2°C and third consecutive day with mean daily temperatures above 5°C and 2°C.
[4]Date of third consecutive day having mean daily temperatures above 5°C and 2°C.

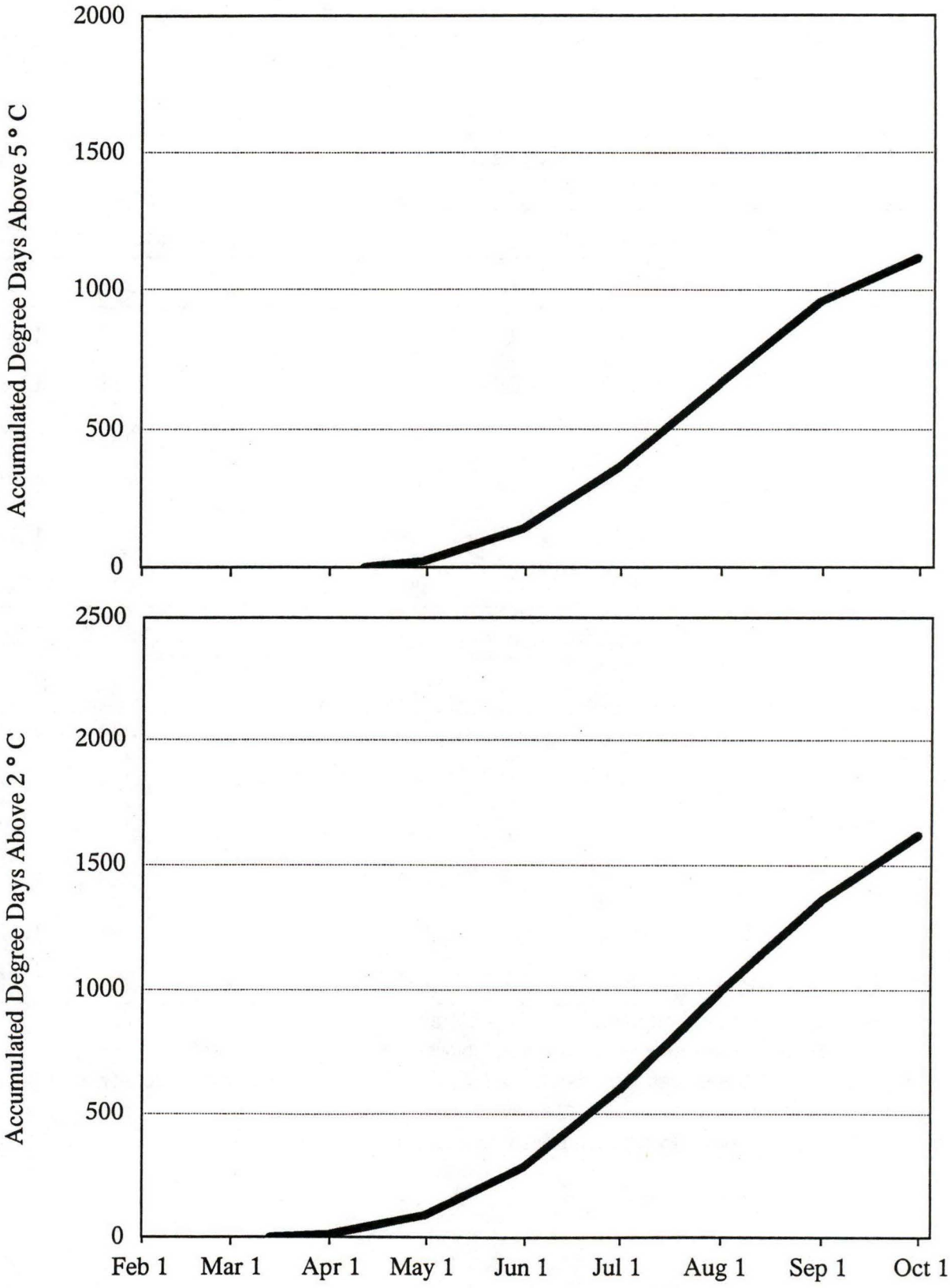

Figure 4. Average accumulated heating degree days above 5° C and 2° C mean daily temperatures starting after the third consecutive day above 5° C and 2° C. Brushy Fork study area, Idaho.

Table 7. Accumulated heating degree-days above 5°C and 2°C mean daily temperatures, Cairn Creek study area, Idaho.[1]

Year	First day over 5°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (5°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1986	2/24	19	3/28	10	65	432	783	1083	1539	1682
1987	2/05	9	2/07	24	150	352	691	1013	1382	1726
1988	1/28	9	2/26	22	102	240	529	903	1305	1553
1989	3/10	5	3/12	0	58	177	449	871	1179	1436
1990	3/18	12	3/31	6	75	166	415	825	1218	1562
Aug	2/22	11	3/09	12	90	273	573	939	1325	1592
Year	First day over 2°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (2°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1986	2/01	10	2/26	83	200	659	1100	1493	2042	2275
1987	1/11	23	2/07	70	267	554	983	1398	1860	2293
1988	1/27	30	2/26	47	180	395	775	1242	1747	2071
1989	1/30	14	3/11	6	132	329	691	1206	1607	1953
1990	1/12	5	3/02	57	194	359	692	1196	1682	316
Aug	1/22	16	2/26	53	195	459	848	1307	1788	2142

[1]Mean daily temperatures based on average daily maximum and minimum temperatures.
[2]Accumulated degree-days starting after third consecutive day above 5°C or 2°C.
[3]Degree-days accumulated between first day above 5°C or 2°C and third consecutive day with mean daily temperatures above 5°C or 2°C.
[4]Date of third consecutive day having mean daily temperatures above 5°C or 2°C.

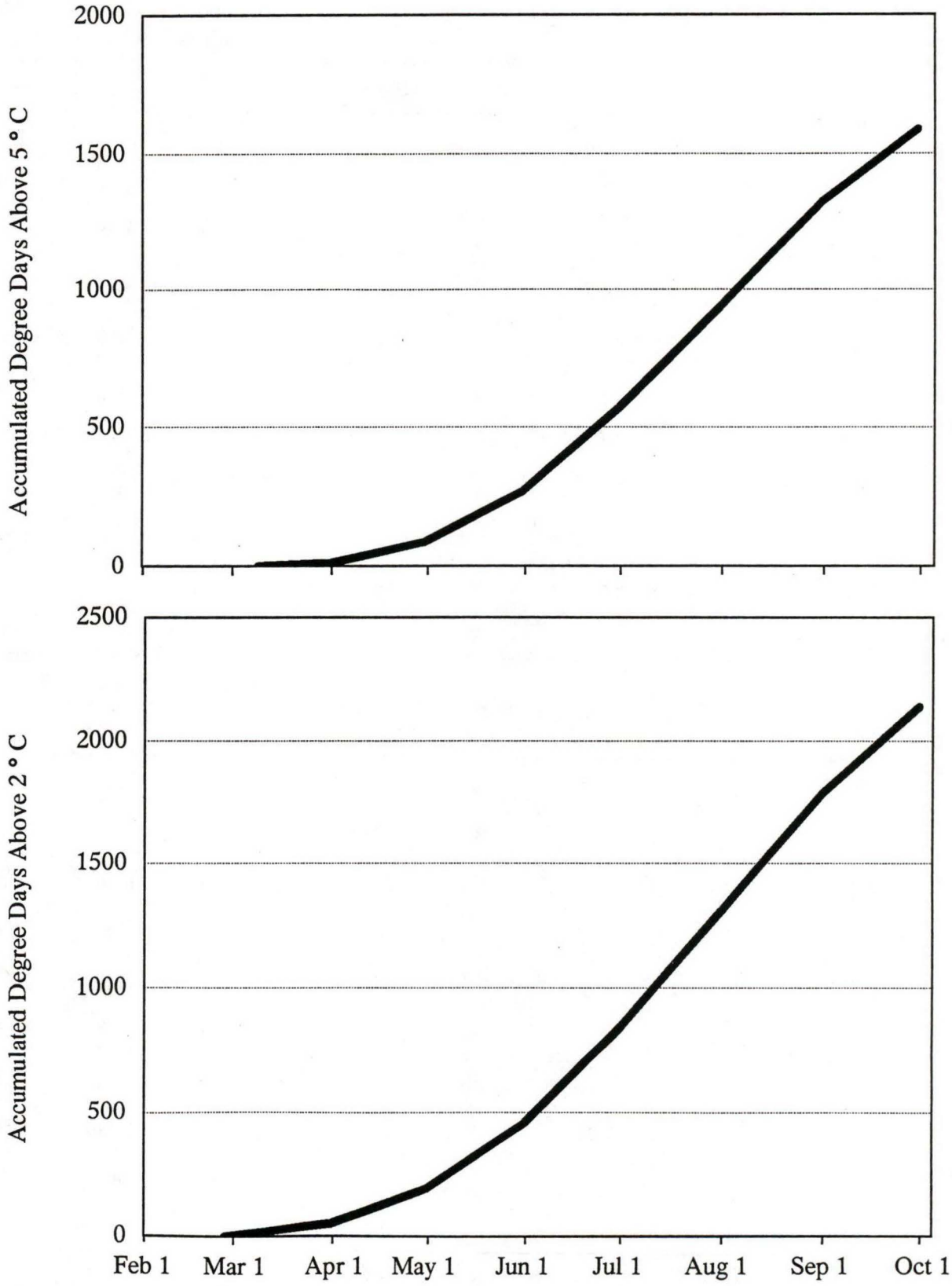

Figure 5. Average accumulated heating degree days above 5° C and 2° C mean daily temperatures starting after the third consecutive day above 5° C and 2° C. Cairn Creek study area, Idaho.

Table 8. Accumulated heating degree-days above 5°C and 2°C mean daily temperatures, Ericson Ridge study area, Idaho.[1]

Year	First day over 5°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (5°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1985	4/01	3	4/03	0	71	236	501	931	1199	1287
1986	1/10	12	3/01	14	44	228	554	826	1230	1335
1987	2/06	17	4/02	0	104	284	583	888	1191	1426
1988	2/25	3	2/27	9	81	205	491	843	1195	1391
1989	3/09	13	4/07	0	49	147	390	784	1088	1299
1990	3/07	16	4/02	0	64	147	382	746	1084	1382
1991	3/31	11	4/22	0	8	104	269	638	1029	1258
1992	1/31	6	2/29	20	88	290	565	869	1202	1378
1993	3/06	15	5/03	0	0	218	385	578	853	1032
1994	3/01	6	3/03	9	60	202	420			
Aug	2/26	10	3/26	5	57	206	454	789	1119	1310
Year	First day over 2°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (2°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1985	3/01	5	3/19	7	145	392	747	1271	1631	1799
1986	1/10	11	1/31	80	149	399	815	1182	1677	1864
1987	1/11	14	2/07	54	232	502	892	1290	1686	2011
1988	1/27	4	1/29	53	184	380	756	1189	1645	1928
1989	1/20	19	3/11	12	137	311	643	1130	1527	1828
1990	1/09	10	2/24	46	183	338	665	1122	1553	1940
1991	2/02	4	2/04	28	91	274	530	991	1476	1794
1992	1/10	10	2/01	109	234	528	892	1290	1714	1978
1993	2/04	14	3/07	23	62	368	624	909	1278	1541
1994	2/15	5	2/17	51	151	385	689			
Aug	1/26	10	2/17	46	157	388	725	1153	1576	1854

[1] Mean daily temperature based on average of daily maximum and minimum temperatures.
[2] Accumulated degree-days starting after third consecutive day above 5°C or 2°C.
[3] Degree-days accumulated between first day above 5°C or 2°C and third consecutive day with mean daily temperatures above 5°C or 2°C.
[4] Date of third consecutive day having mean daily temperatures above 5°C or 2°C.

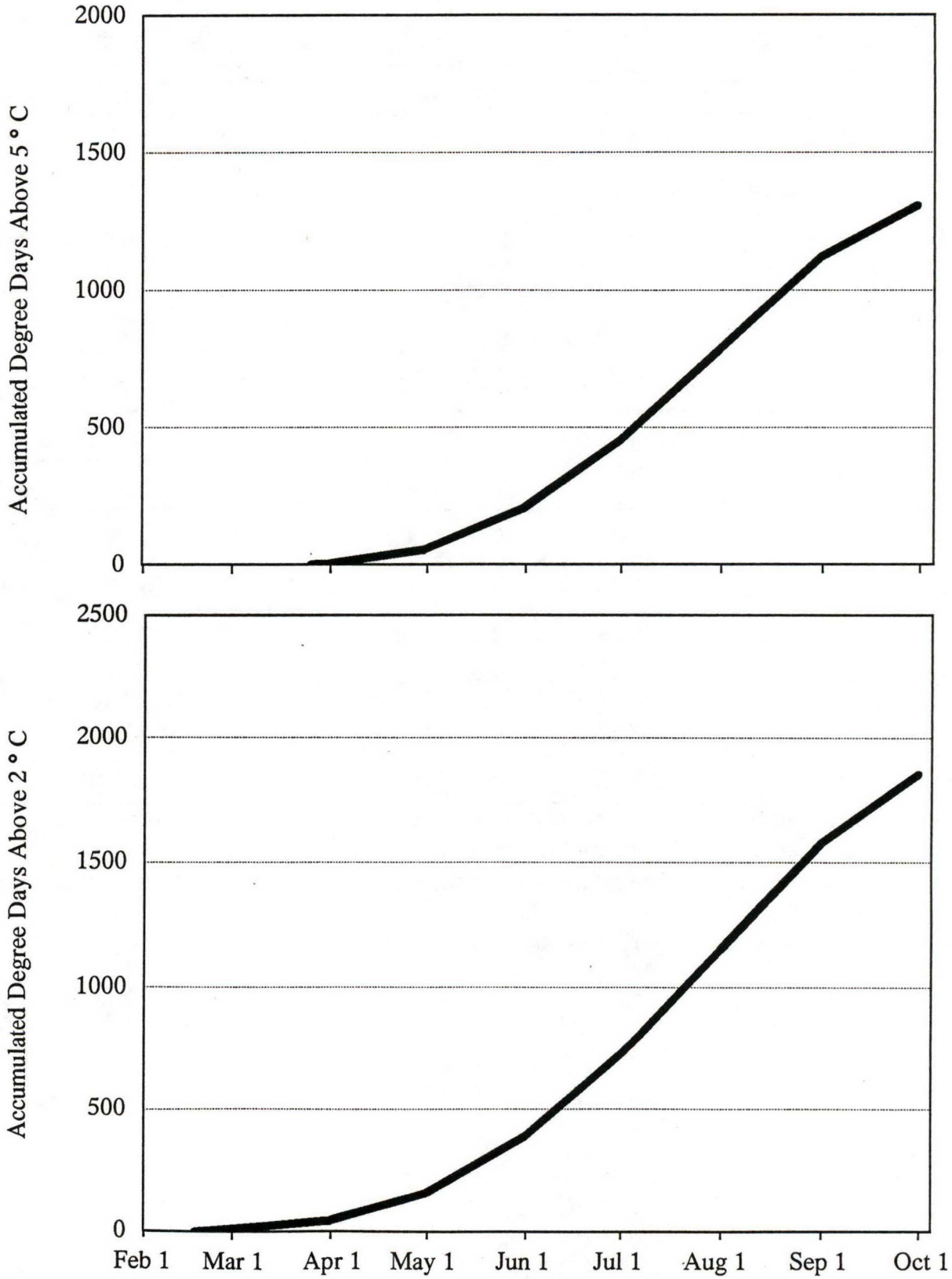

Figure 6. Average accumulated heating degree days above 5° C and 2° C mean daily temperatures starting after the third consecutive day above 5° C and 2° C. Ericson Ridge study area, Idaho.

Table 9. Accumulated heating degree-days above 5°C and 2°C mean daily temperatures, Meadow Creek study area, Idaho.[1]

Year	First day over 5°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (5°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1985	3/20	13	4/03	0	81	300	609	1097	1441	1589
1986	2/25	24	3/29	2	50	270	629	938	1398	1540
1987	3/04	15	4/03	0	103	317	674	1042	1397	1678
1988	2/12	3	3/21	4	105	295	603	997	1399	1626
1989	1/30	14	4/12	0	77	233	547	975	1320	1540
Aug	2/23	14	3/31	1	83	283	612	1010	1391	1595
Year	First day over 2°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (2°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1985	2/15	9	3/18	17	183	495	893	1475	1911	2145
1986	2/24	9	2/26	75	194	506	954	1357	1910	2141
1987	2/01	15	3/05	34	230	537	973	1445	1893	2274
1988	1/29	7	2/13	50	218	499	898	1384	1880	2197
1989	1/04	13	3/11	16	184	433	836	1358	1795	2113
Aug	2/02	11	3/03	38	202	494	911	1404	1878	2174

[1]Mean daily temperatures based on average of daily maximum and minimum temperatures.
[2]Accumulated degree-days starting after third consecutive day above 5°C or 2°C.
[3]Degree-days accumulated between first day above 5°C or 2°C and third consecutive day with mean daily temperatures above 5°C and 2°C.
[4]Date of third consecutive day having mean daily temperature above 5°C or 2°C.

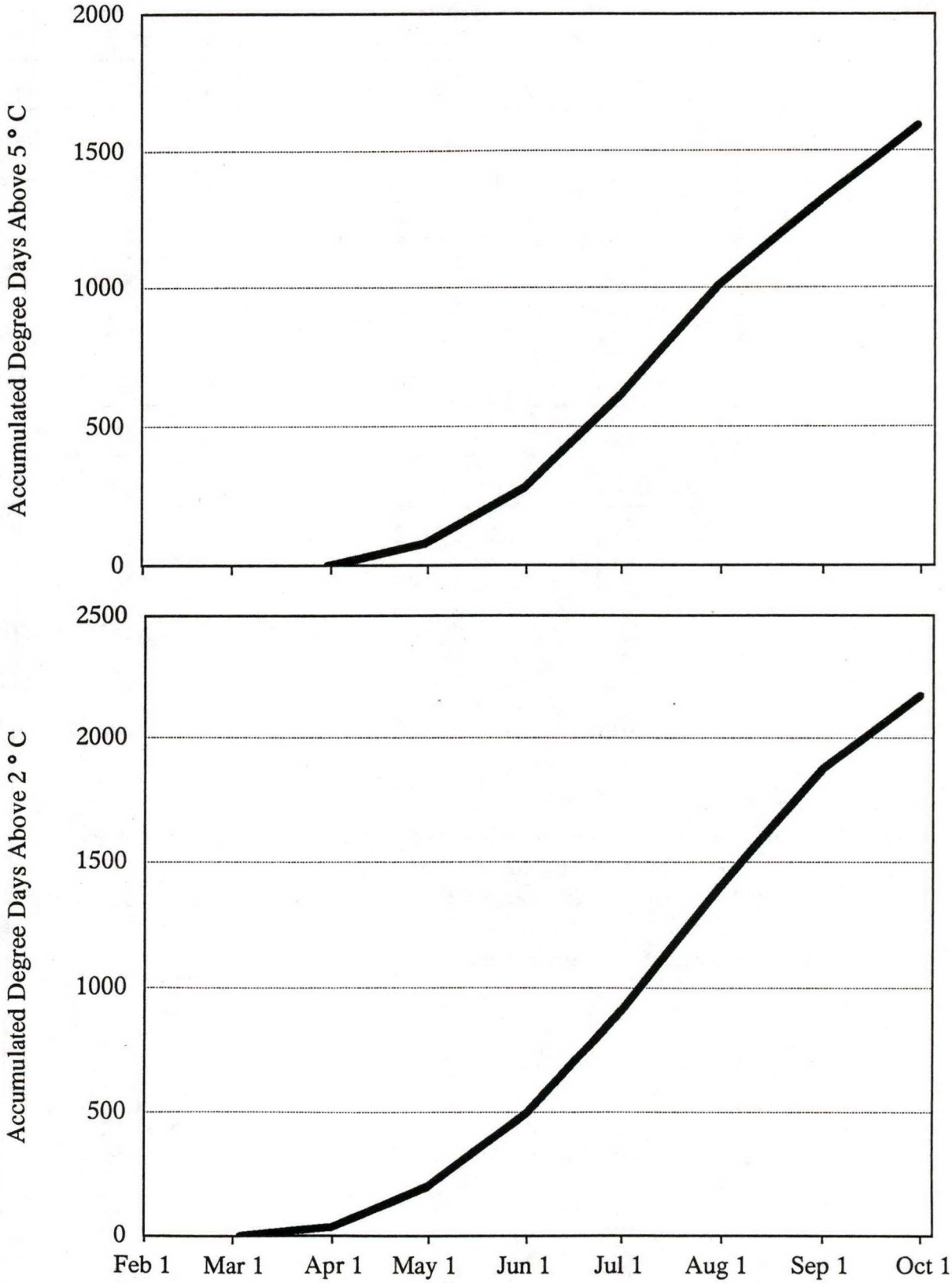

Figure 7. Average accumulated heating degree days above 5° C and 2° C mean daily temperatures starting after the third consecutive day above 5° C and 2° C. Meadow Creek study area, Idaho.

Table 10. Accumulated heating degree-days above 5°C and 2°C mean daily temperature, Peter Ready Creek study area, Idaho.[1]

Year	First day over 5°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (5°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1985	3/17	16	4/02	0	102	408	682	1153	1462	1574
1986	2/24	12	2/26	31	53	222	514	777	1195	1282
1987	2/06	4	2/08	9	110	267	544	825	1154	1433
1988	2/25	5	2/27	9	70	179	433	793	1165	1380
1989	3/09	4	3/11	1	56	132	354	739	1034	1239
Aug	2/27	8	3/04	10	78	242	505	857	1202	1382
Year	First day over 2°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (2°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1985	2/15	12	3/18	22	192	591	954	1518	1920	2113
1986	2/02	23	2/25	85	145	372	754	1107	1618	1767
1987	1/11	13	2/07	40	203	440	807	1181	1603	1967
1988	1/27	19	2/26	36	147	321	664	1117	1582	1880
1989	1/30	14	3/11	6	119	256	566	1044	1432	1727
Aug	1/29	16	3/01	38	161	396	749	1193	1631	1891

[1]Mean daily temperatures based on average of daily maximum and minimum temperatures.
[2]Accumulated degree-days starting after third consecutive day above 5°Cor 2°C.
[3]Degree-days accumulated between first day above 5°C or 2°C and third consecutive day with mean daily temperatures above 5°C or 2°C.
[4]Date of third consecutive day having mean daily temperatures above 5°C or 2°C.

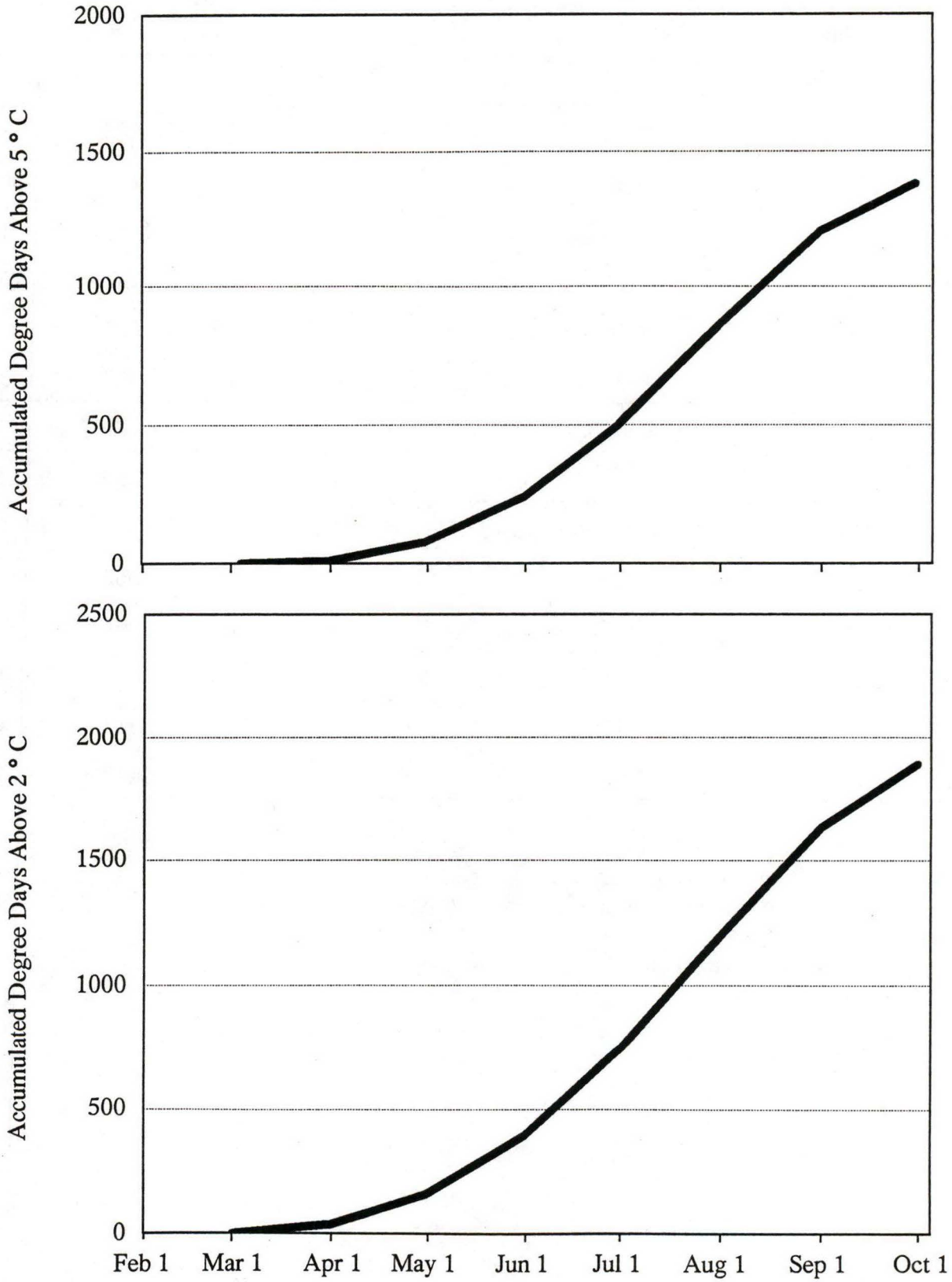

Figure 8. Average accumulated heating degree days above 5° C and 2° C mean daily temperatures starting after the third consecutive day above 5° C and 2° C. Peter Ready Creek study area, Idaho.

Table 11. Accumulated heating degree-days above 5°C and 2°C mean daily temperatures, Twin Creeks study area, Idaho.[1]

Year	First day over 5°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (5°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1985	4/01	7	4/07	0	77	279	570	1083	1411	1547
1986	3/20	15	3/29	0	50	276	627	950	1438	1588
1987	3/04	12	4/02	0	136	362	717	1085	1461	1768
1988	2/21	2	3/01	7	111	290	592	988	1410	1662
1989	1/30	4	4/08	0	90	257	580	1007	1347	1596
Aug	3/04	8	3/28	1	93	293	617	1023	1413	1632
Year	First day over 2°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (2°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1985	2/15	4	3/16	14	172	464	844	1450	1871	2096
1986	2/24	8	2/26	63	186	504	946	1362	1942	2182
1987	1/28	12	3/05	48	273	591	1036	1498	1967	2363
1988	1/29	15	2/28	42	218	488	880	1369	1884	2226
1989	1/04	16	3/11	17	190	450	862	1383	1816	2155
Aug	2/01	11	3/06	37	208	499	914	1412	1896	2204

[1]Mean daily temperatures based on average daily maximum and minimum temperatures.
[2]Accumulated degree-days starting after third consecutive day above 5°C or 2°C.
[3]Degree-days accumulated between first day above 5°C or 2°C and third consecutive day with mean daily temperature above 5°C or 2°C.
[4]Date of third consecutive day having mean daily temperature above 5°C or 2°C.

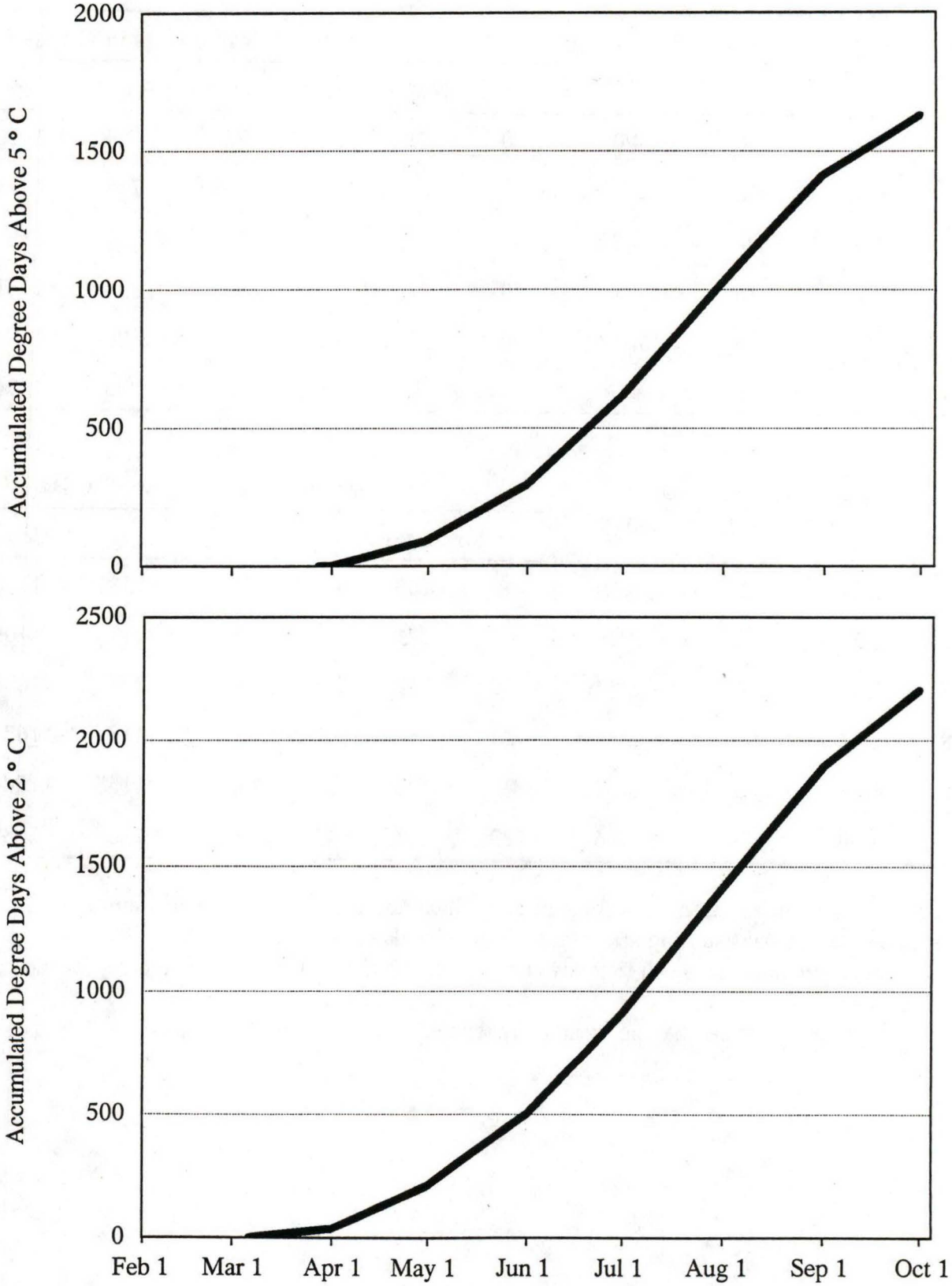

Figure 9. Average accumulated heating degree days above 5° C and 2° C mean daily temperatures starting after the third consecutive day above 5° C and 2° C. Twin Creeks study area, Idaho.

Table 12. Accumulated heating degree-days above 5°C and 2°C mean daily temperatures, Standard Creek study area, Montana.[1]

Year	First day over 5°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (5°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1985	4/01	4	4/03	0	72	506	765	1178	1470	1598
1986	3/01	16	3/29	0	47	226	533	796	1214	1311
1987	3/04	6	4/02	0	93	269	572	887	1181	1426
1988	2/12	16	4/12	0	54	191	478	814	1161	1357
1989	1/30	16	4/14	0	38	146	415	800	1093	1279
Aug	2/26	12	4/06	0	61	268	553	895	1224	1394

Year	First day over 2°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (2°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1985	2/24	5	3/19	8	149	676	1025	1531	1916	2125
1986	2/24	6	2/26	69	181	444	842	1198	1709	1894
1987	3/02	7	3/04	31	197	466	859	1267	1653	1989
1988	1/28	19	2/28	26	152	378	755	1184	1624	1910
1989	1/03	21	3/12	9	126	321	680	1158	1544	1819
Aug	2/09	12	3/06	29	161	457	832	1268	1689	1947

[1]Mean daily temperatures based on average of daily maximum and minimum temperatures.
[2]Accumulated degree-days starting after third consecutive day above 5°C or 2°C.
[3]Degree-days accumulated between first day above 5°C or 2°C and third consecutive day with mean daily temperatures above 5°C or 2°C.
[4]Date of third consecutive day having mean daily temperatures above 5°C or 2°C.

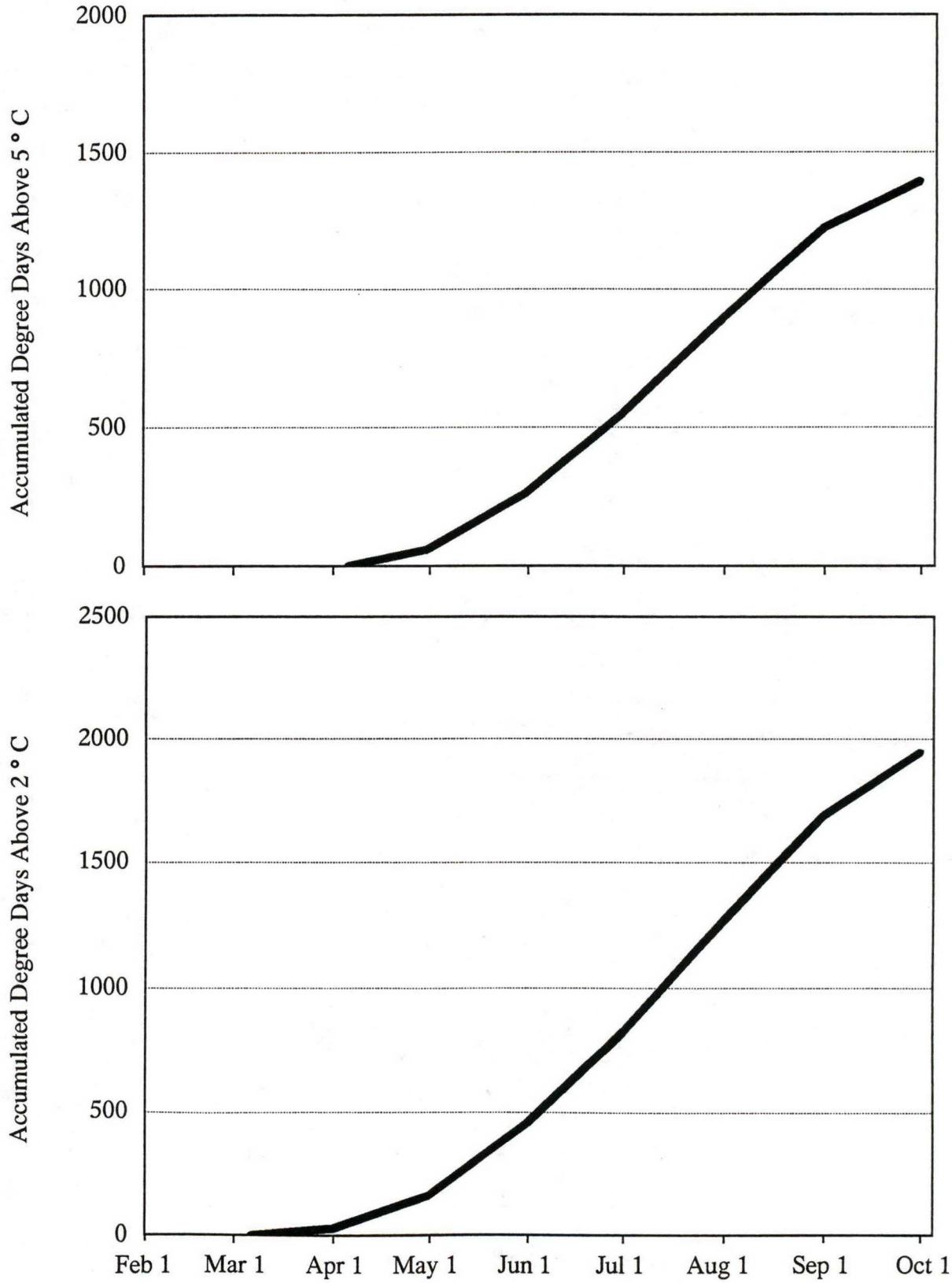

Figure 10. Average accumulated heating degree days above 5° C and 2° C mean daily temperatures starting after the third consecutive day above 5° C and 2° C. Standard Creek study area, Montana.

Table 13. Accumulated heating degree-days above 5°C and 2°C mean daily temperatures, Twelvemile Creek study area, Montana.[1]

Year	First day over 5°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (5°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1985	4/01	6	4/10	0	48	189	397	804	1039	1102
1986	3/27	2	4/09	0	7	145	423	667	1059	1127
1987	4/03	2	4/05	0	52	194	462	736	1008	1224
1988	4/06	6	4/13	0	15	112	360	668	997	1116
1989	4/06	3	4/14	0	14	81	297	651	898	1040
1990	3/31	3	4/02	0	12	55	242	573	885	1155
1991	4/01	7	4/21	0	3	74	212	542	891	1088
1992	3/01	2	3/14	4	63	225	509	793	1081	1179
1993	3/22	22	5/11	0	0	144	294	440	674	808
1994	3/01	8	4/17	0	16	139	320	682	1034	1242
Aug	3/25	5	4/12	0	23	136	352	656	957	1108

Year	First day over 2°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (2°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1985	2/24	10	4/03	0	102	327	625	1125	1453	1588
1986	2/24	6	3/08	10	43	249	617	954	1439	1590
1987	3/04	8	4/02	0	113	340	697	1064	1430	1735
1988	3/02	6	3/20	1	70	247	585	986	1408	1658
1989	1/30	5	3/12	0	69	212	518	965	1305	1537
1990	3/19	2	3/21	10	79	192	466	890	1294	1654
1991	1/13	7	2/05	15	61	211	439	862	1314	1591
1992	2/01	11	3/01	49	171	423	797	1174	1551	1731
1993	3/04	4	3/06	21	56	305	539	779	1105	1322
1994	2/28	11	3/29	8	78	292	560	1015	1461	1759
Aug	2/20	7	3/14	11	84	280	584	981	1376	1616

[1]Mean daily temperatures based on average of daily maximum and minimum temperatures.
[2]Accumulated degree-days starting after third consecutive day above 5°C or 2°C.
[3]Degree-days accumulated between first day above 5°C or 2°C and third consecutive day with mean daily temperatures above 5°C or 2°C.
[4]Date of third consecutive day having mean daily temperatures above 5°C or 2°C.

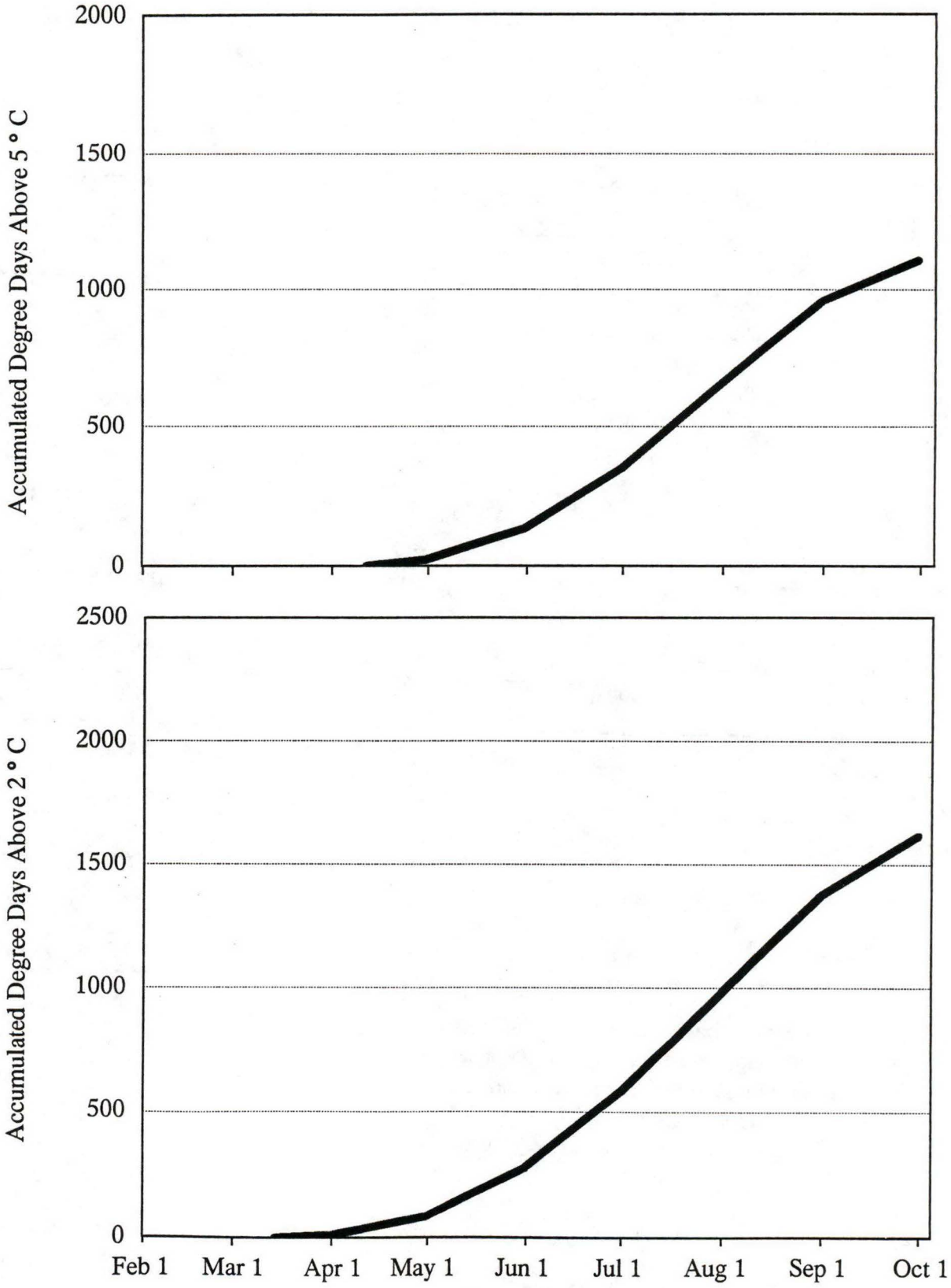

Figure 11. Average accumulated heating degree days above 5° C and 2° C mean daily temperatures starting after the third consecutive day above 5° C and 2° C. Twelvemile Creek study area, Montana.

Table 14. Accumulated heating degree-days above 5°C or 2°C mean daily temperatures, Catherine Summit study area, Oregon.[1]

Year	First day over 5°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (5°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1988	2/20	3	2/28	12	94	223	555	975	1393	1638
1989	3/11	18	4/07	0	77	215	482	879	1148	1377
1990	3/17	8	3/19	16	125	232	501	941	1354	1726
1991	3/31	27	4/21	0	16	115	307	817	1344	1600
Aug	3/13	14	3/27	7	78	196	461	903	1310	1585

Year	First day over 2°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (2°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1988	2/20	11	2/26	48	195	448	829	1342	1854	2188
1989	3/06	2	3/08	29	199	423	776	1266	1616	1932
1990	2/10	17	3/18	47	231	423	782	1315	1821	2283
1991	1/13	8	2/22	24	109	297	578	1181	1801	2147
Aug	2/12	10	3/04	37	184	398	741	1276	1773	2138

[1]Mean daily temperatures based on average of daily maximum and minimum temperatures.
[2]Accumulated degree-days starting after third consecutive day above 5°C or 2°C.
[3]Degree-days accumulated between first day above 5°C or 2°C and third consecutive day with mean daily temperatures above 5°C or 2°C.
[4]Date of third consecutive day having mean daily temperature above 5°C or 2°C.

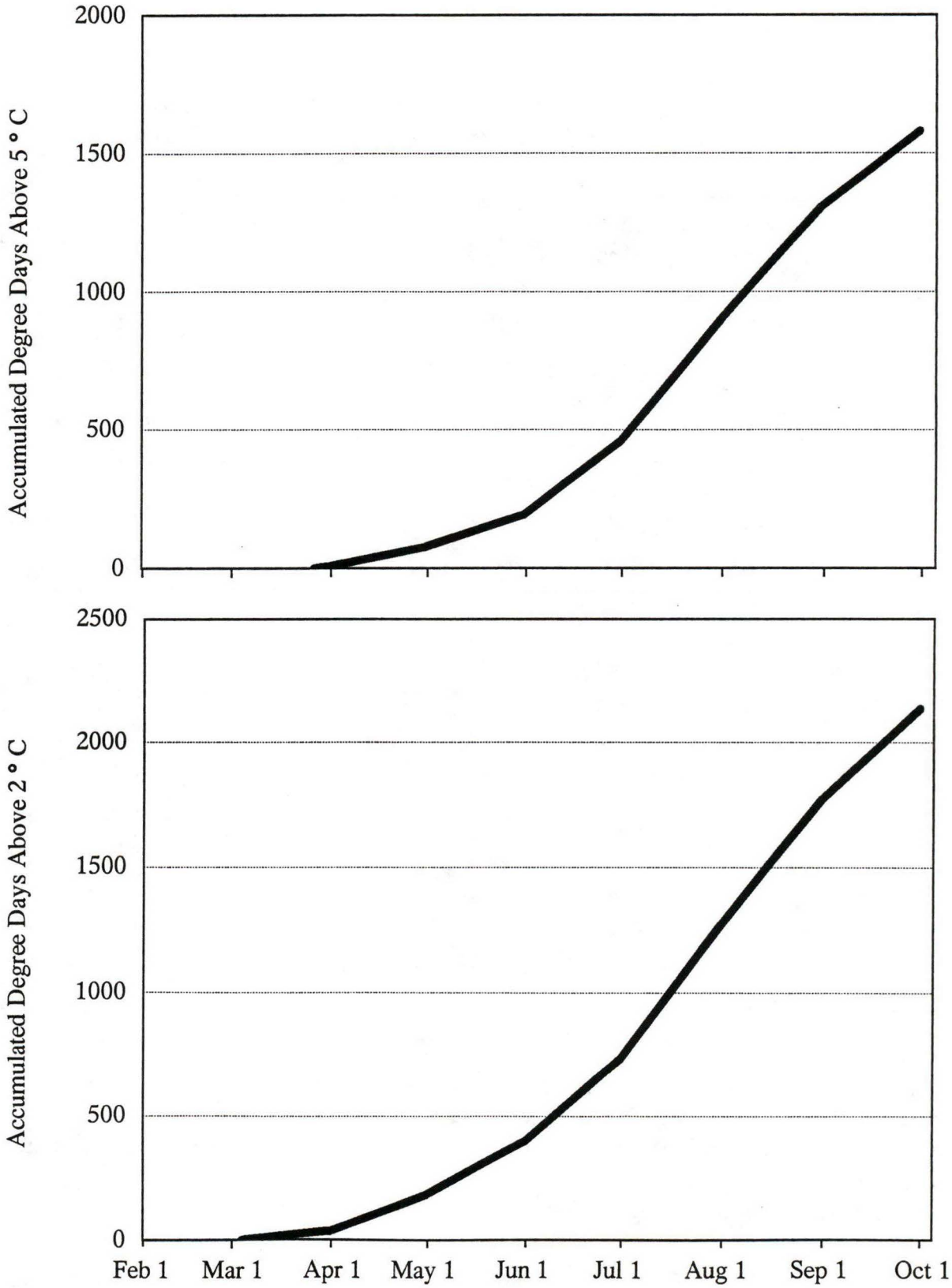

Figure 12. Average accumulated heating degree days above 5° C and 2° C mean daily temperatures starting after the third consecutive day above 5° C and 2° C. Catherine Summit study area, Oregon.

Table 15. Accumulated heating degree-days above 5°C and 2°C mean daily temperatures, Crystal Springs study area, Oregon.[1]

Year	First day over 5°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (5°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1987	3/02	4	3/04	9	99	247	520	773	1064	1286
1988	2/25	3	2/27	12	77	187	404	723	1008	1181
1989	3/09	4	3/11	4	77	166	382	675	931	1096
1990	1/09	6	3/19	10	79	145	355	695	1007	1248
1991	2/02	16	4/23	0	0	40	155	456	796	1003
Aug	2/14	7	3/17	7	66	157	363	664	961	1163

Year	First day over 2°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (2°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1987	2/04	13	3/03	36	202	436	799	1145	1529	1841
1988	2/08	3	2/10	76	199	388	693	1105	1483	1745
1989	1/08	13	3/06	35	180	347	653	1039	1388	1842
1990	1/06	3	1/08	75	222	367	668	1101	1496	1836
1991	1/11	12	2/02	50	95	212	412	806	1239	1536
Aug	1/20	9	2/11	54	180	350	645	1039	1427	1760

[1]Mean daily temperatures based on average of daily maximum and minimum temperatures.
[2]Accumulated degree-days starting after third consecutive day above 5°C or 2°C.
[3]Degree-days accumulated between first day above 5°C or 2°C and third consecutive day with mean daily temperatures above 5°C or 2°C.
[4]Date of third consecutive day having mean daily temperatures above 5°C or 2°C.

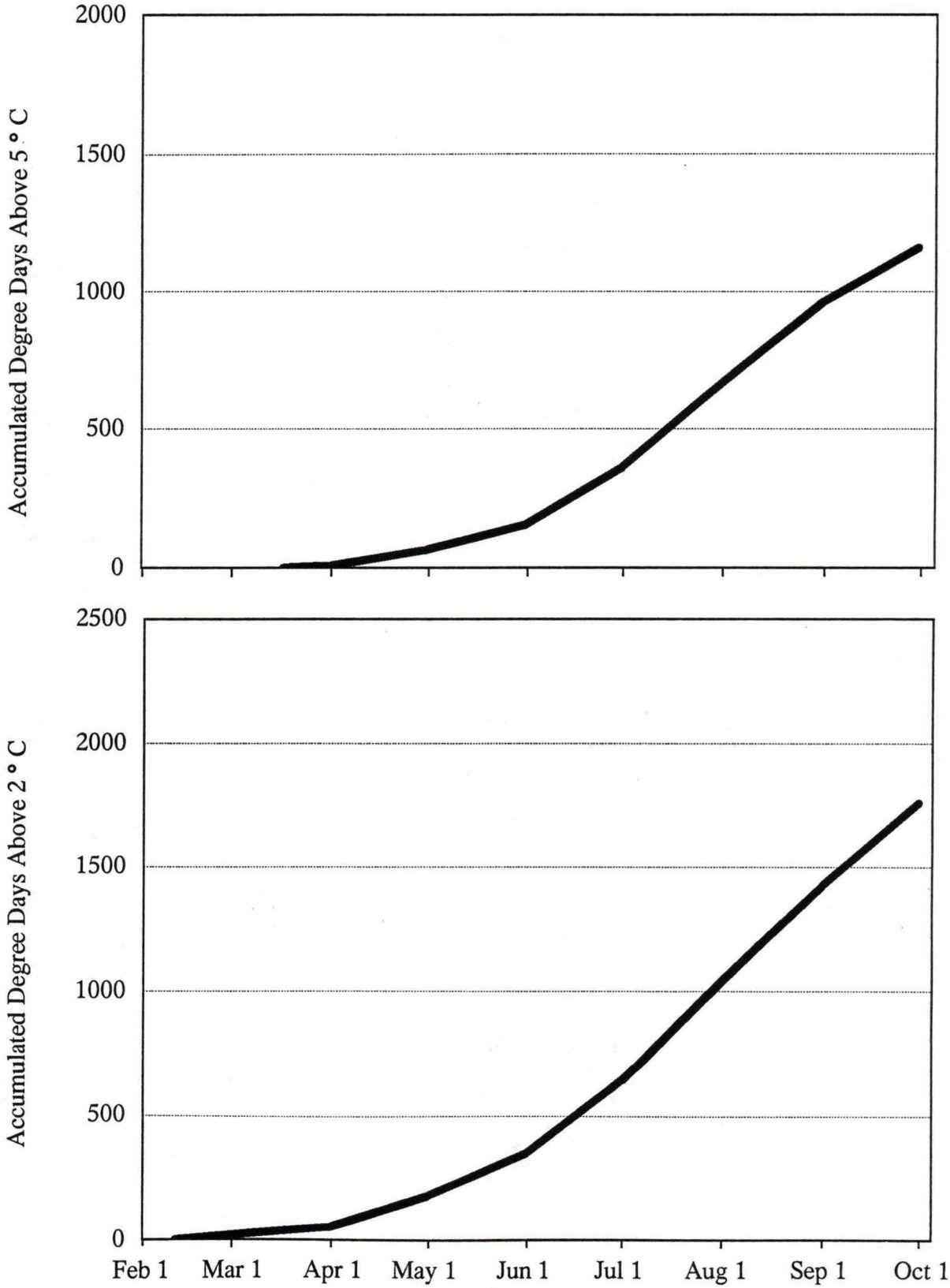

Figure 13. Average accumulated heating degree days above 5° C and 2° C mean daily temperatures starting after the third consecutive day above 5° C and 2° C. Crystal Springs study area, Oregon.

Table 16. Accumulated heating degree-days above 5°C and 2°C mean daily temperatures, Sleeping Beauty study area, Washington.[1]

Year	First day over 5°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (5°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1987	3/31	9	4/02	0	91	284	593	902	1260	1331
1988	2/11	3	2/21	20	92	232	461	804	1144	1380
1989	4/05	8	4/07	0	76	207	463	758	1055	1273
1990	2/24	5	3/19	20	113	223	461	858	1211	1507
Aug	3/11	6	3/21	10	93	236	494	830	1168	1373

Year	First day over 2°C	Accum °Day[3]	Date of 3rd Consec[4]	Accumulated Degree-Days (2°C Base)[2]						
				Apr 1	May 1	Jun 1	Jul 1	Aug 1	Sep 1	Oct 1
1987	2/01	10	3/05	39	214	499	899	1301	1752	2112
1988	1/14	12	2/12	86	231	454	773	1210	1642	1968
1989	1/02	3	1/04	26	192	416	762	1150	1545	1847
1990	1/04	4	1/06	90	267	466	794	1284	1731	2117
Aug	1/13	7	1/29	60	226	459	807	1236	1668	2011

[1]Mean daily temperatures based on average of daily maximum and minimum temperatures.
[2]Accumulated degree-days starting after third consecutive day above 5°C or 2°C.
[3]Degree-days accumulated between first day above 5°C or 2°C and third consecutive day with mean daily temperatures above 5°C or 2°C.
[4]Date of third consecutive day having mean daily temperatures above 5°C or 2°C.

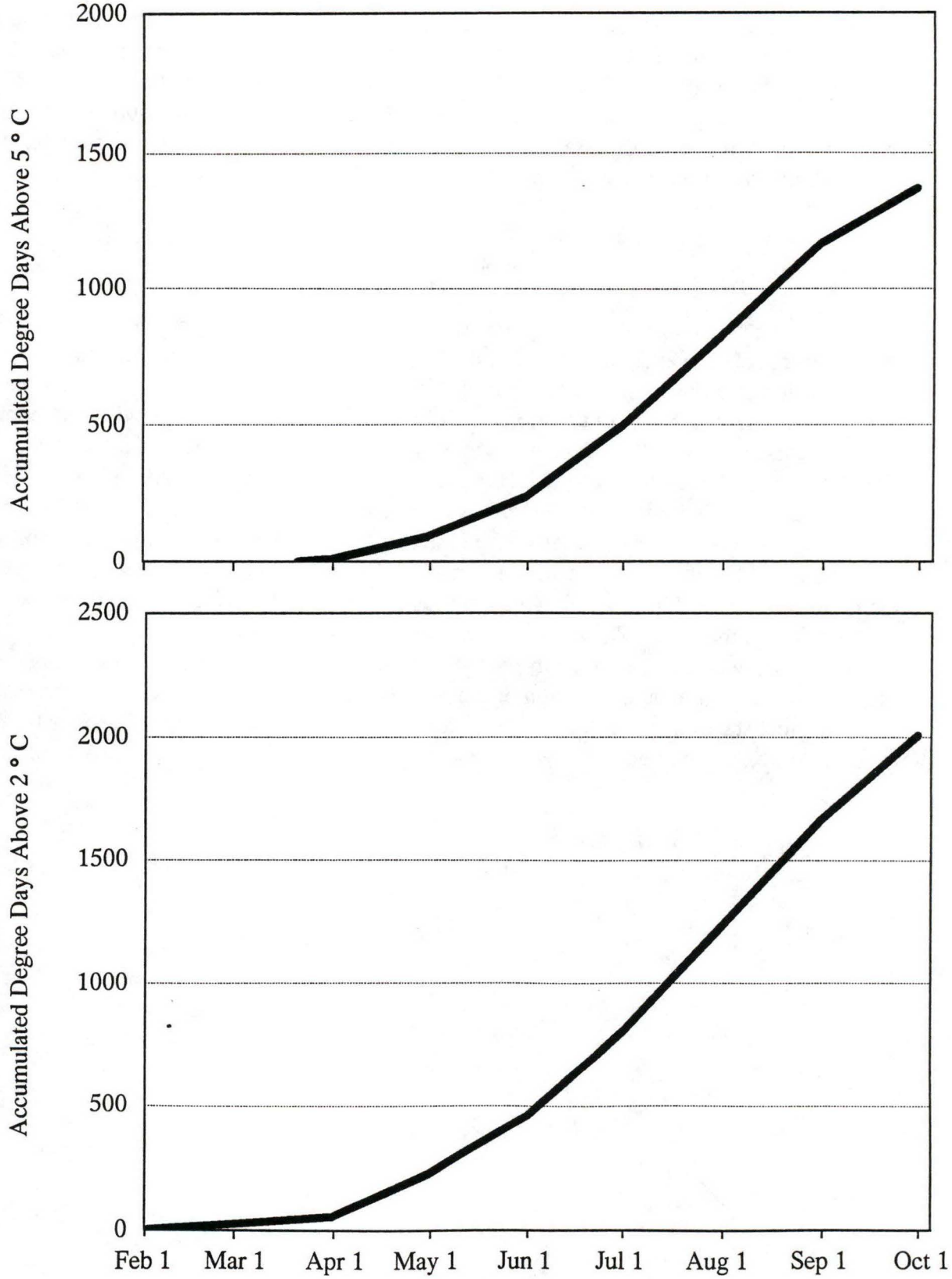

Figure 14. Average accumulated heating degree days above 5° C and 2° C mean daily temperatures starting after the third consecutive day above 5° C and 2° C. Sleeping Beauty study area, Washington.

Cone Production

For each study area, the potential number of seed cones, stages of development, insect damage and the number of mature cones that survived were obtained from previous publications and reports by Shearer and Theroux, 1985; Shearer and Theroux, 1986; Shearer, 1989; Theroux, 1994. Table 17 summarizes the number of potential cones and estimated number of mature cones for the fourteen study areas for 1985 through 1994. Occasional field notes also identified dates when frost or insect damage may have occurred.

Phenology and Degree-Days

Direct phenological observations were not collected in this or previous studies, so it was necessary to relate average accumulated degree-days at study sites to calendar days for the Northern Idaho and Montana sites for 1985-1994. Dates of phenological events for western larch summarized in Schmidt and Lotan (1980) for 1928-1937, dates for bud-burst reported in Shearer and Carlson (1991), dates of various phenological stages from unpublished data for 1912-1916, and 1928-1937, and from Owens (1979) were summarized and related to degree-days accumulations for the six Northern Idaho and Montana study sites. The date at which larch would break dormancy obtained from 2°C threshold appeared to be much earlier than field observations. For this reason, it was assumed that larch would break dormancy after three consecutive days with mean daily temperatures above 5°C. The accumulated degree-days were also started on that date. These comparisons are shown in Table 18. It should be noted that there is considerable variation from year to year in dates of various phenological stages depending on location and elevation of the larch stand. On any individual year, various phenological stages may be over a month earlier or later than the average date shown in table 18. It is suggested that degree-days be used to estimate phenological stages rather than calender dates.

Table 17. Mean number of western larch seed cones estimated per sample tree: Potential (P) estimated in the spring and Mature (M) estimated summer by year and study area location.

Site No.	Study Area	Cones	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
						IDAHO						
3	Beacon Light	P	828	1000	927	1090	1450	151	1362	121	678	89
		M	130	0	555	10	680	0	627	0	542	74
7	Brush Mountain	P	319	487	160	797	2995					
		M	0	0	50	2	1171					
10	Brushy Fork	P		279	1940	1186	2015	1547	1694	21	1387	1
		M		0	44	16	0	0	1614	6	1334	1
11	Cairn Creek	P		313	162	913	1601	489				
		M		0	62	0	1041	0				
5	Ericson Ridge	P	981	1528	300	1133	2073	545	459	0	2890	16
		M	0	0	210	2	0	0	443	0	1005	15
1	Meadow Creek	P	1220	2840	2108	3029	3150					
		M	173	2	818	1062	177					
6	Peter Ready Creek	P	1270	1181	489	1147	2576					
		M	0	0	190	28	0					
4	Savage Camp	P	163	111	2	45	667					
		M	0	0	0	0	0					
2	Twin Creeks	P	656	56	476	317	269					
		M	0	56	136	38	44					
						MONTANA						
9	Standard Creek	P	199	24	22	124	196					
		M	4	0	21	11	132					
8	Twelvemile Creek	P	267	296	264	510	562	562	714	53	370	1
		M	40	0	175	0	391	0	471	4	265	0
						OREGON						
14	Catherine Summit	P				2314	11224	698	1464			
		M				0	8820	0	329			
12	Crystal Springs	P			1536	11286	6546	4343	3212			
		M			814	434	728	0	3021			
						WASHINGTON						
13	Sleeping Beauty	P			1681	465	3824	480	2488			
		M			1363	169	2361	351	2261			

Table 18. Phenological stages of western larch and average accumulated heating degree-days above 5°C mean daily temperature for study sites in Northern Idaho and Montana.

Phenological Stage	Average Date[1]	Julian Day	Accumulated Degree-Days[2]
Break Dormancy	3/29	88	0
Pollen Cone Bud Burst	4/12	102	11
Seed Cone Bud Burst	4/12	102	11
Leaf Bud Swell	4/15	105	16
Pollen Dispersal Starts*	4/18	108	23
Pollen Dispersal Ends	5/25	145	193
Bark Slip	4/22	112	34
Leaf Bud Burst	4/26	116	45
Short Shoots Start	4/12	102	11
Short Shoots End	6/22	173	427
Long Shoots Start	5/13	133	120
Long Shoots End	7/27	208	820
Cones Full Size	7/01	182	520
Embryos Fully Developed	8/21	233	1110
Cones Open	9/01	244	1240
Winter Bud Formed	8/19	231	1085
Bark Sticks	8/21	233	1110

[1]Dates of phenological stages for western larch from Schmidt and Lotan (1980), from study sites (Shearer and Carlson 1991), from 1912-1916 unpublished data, and from Owen (1979). There is considerable variation in these dates for individual years and for larch at different locations and elevations.

[2]Based on 40 site-year temperature records for six study sites in Northern Idaho and Montana (Beacon Light 1985-94; Cairn Creek 1986-90; Meadow Creek 1985-89; Standard Creek 1985-89; Twelvemile Creek 1985-94; and Twin Creeks 1985-89) with accumulation starting after three consecutive days with mean daily temperatures above 5°C.

*Based on field observations made during visits to the study sites, it appears pollen dispersal starts earlier than reported in other studies.

Comparison of Temperature and Cone Production

There were 81 individual years of data where both temperatures and cone production records were available for the 13 study sites. Using the 2°C base to indicate when the trees breaks dormancy provides dates much earlier in the spring than would be expected from general observations. It was assumed for this study that the 5°C base better represents the threshold for breaking dormancy.

Days when the minimum temperature was below -3°C, occurring after three consecutive days with mean daily temperatures above 5°C, and the estimated phenological stage at the time of low temperatures, were identified for all study sites (Tables 19 through 31). By comparing field notes on frost damage, percent of potential cones which mature and daily minimum temperatures below -3°C occurring after trees break dormancy (three consecutive days with above 5°C mean daily temperature) and accumulated degree-days, certain relationships appear to exist. Minimum daily temperatures lower than -4°C after the tree breaks dormancy and prior to seed cone and pollen cone bud-burst (up to approximately 10 accumulated degree-days) had little effect on cone survival. Minimum daily temperatures lower than -4°C from seed cone and pollen cone bud-burst up through the end of pollen dispersal (between approximately 11 to 215 accumulated degree days) resulted in a major loss of mature cones. Temperatures close to -4°C during this period (-3.5 to -3.9) had limited reduction in cone survival. Low temperatures after approximately 215 degree-days have accumulated did not appear to affect cone survival. Also, after 215 degree-days had accumulated (usually around the end of May or early June) temperatures rarely drop below the freezing point.

Table 32 summarizes the relationship between minimum temperatures that will cause major damage to cone development, accumulated degree-days after three consecutive days with above 5°C mean daily temperatures and phenological stage for western larch.

A summary of individual years at individual study sites indicated temperature limitations on cone maturity would be in error in 11 percent of the cases (Table 33). The majority of those cases are for study sites in Oregon and Washington. Temperatures correctly indicated cone maturity in 60 percent of the cases and indicated a few cones might be produced when none were anticipated or none might be produced when a few were anticipated in 29 percent of the cases.

It is suspected that low potential cone crop might also be related to temperatures and moisture from the previous fall and early season temperatures.

The one site in Washington shows temperatures low enough to potentially cause cone damage, but this site had a significant production of mature cones in three of the four years. The reason for this discrepancy is not apparent from data available for this study.

Table 19. Temperatures, dates and accumulated heating degree-days for days where minimum daily temperatures are below -3°C for Beacon Light study area, Idaho.

Year	Date Dormancy Breaks[1]	Minimum Daily Temperatures below -3°C, Date and (Accumulated Degree-Day
1985	4/10	-6.1 4/21 (19)*; -5.6 5/12 (61)
1986	3/29	-5.6 3/31 (0); -4.3 4/13 (9)*; -5.6 4/30 (22)*; -3.3 5/14 (38)
1987	4/02	-4.4 4/13 (8)*; -4.0 4/20 (15)
1988	4/12	-4.1 4/25 (42)*
1989	4/14	None
1990	4/01	-5.7 4/29 (34)*
1991	2/03	-8.8 2/27 (18)*; -3.9 4/13 (23)*; -3.3 4/28 (36)
1992	2/01	-4.6 2/17 (0)*; -5.2 3/28 (63); -7.1 4/08 (87)*; -3.8 4/23 (105); -3.4 4/24 (106); -3.2 5/12 (205)
1993	4/18	-4.4 4/20 (0)
1994	4/17	-3.6 4/28 (25); -3.6 4/29 (27)

[1]Date of third consecutive day where mean daily temperature exceeds 5°C
*More than one day with minimum temperatures below -3°C with same number of accumulated degree-days. Only the lowest temperature is shown.

Table 20. Temperatures, dates and accumulated heating degree-days for days where minimum daily temperatures are below -3°C for Brush Mountain study area, Idaho.

Year	Date Dormancy Breaks[1]	Minimum Daily Temperatures below -3°C, Date and (Accumulated Degree-days)
1985	4/03	-6.1 4/20 (53)*
1986	3/02	-6.9 3/25 (1)*; -4.2 3/31 (14); -4.4 4/13 (28)*; -4.7 4/24 (46)*
1987	4/02	-5.7 4/09 (13); -3.7 4/13 (16)*; -5.9 4/20 (37)*
1988	2/28	-10.5 3/12 (1)*; -7.3 3/31 (6)*; -3.7 4/01 (7); -8.3 4/05 (8)*; -7.3 4/09 (11)*; -3.3 4/26 (76)*; -6.4 5/02 (88)*
1989	4/07	-3.6 4/09 (0); -3.1 5/19 (119)

[1]Date of third consecutive day where mean daily temperature exceeds 5°C
*More than one day with minimum temperature below -3°C with same number of accumulated degree-days. Only the lowest temperature is shown.

Table 21. Temperatures, dates and accumulated heating degree-days for days where minimum daily temperatures are below -3°C for Brushy Fork study area, Idaho.

Year	Date Dormancy Breaks[1]	Minimum Daily Temperatures below -3°C, Date and (Accumulated Degree-day)
1986	3/30	-5.6 4/04 (0)*; -6.7 4/14 (11)*; -6.7 5/01 (21)*; -3.3 5/02 (25); -3.3 5/06 (35); -4.8 5/16 (36); -5.3 5/23 (62)
1987	4/04	-9.7 4/13 (3)*; -3.8 4/14 (4); -8.2 4/20 (8)*; -3.3 4/21 (12); -3.9 5/22 (191); -3.6 6/02 (226)
1988	4/13	-6.1 4/26 (22)*; -3.3 5/18 (70)
1989	4/15	-4.6 4/18 (1); -6.3 4/29 (13)*; -3.7 4/30 (15)*; -4.6 5/12 (51); -4.5 5/20 (65)
1990	4/02	-5.6 4/04 (2)*; -6.3 4/06 (3); -3.2 4/09 (6); -3.3 4/13 (7); -4.7 4/30 (33)*; -5.9 5/09 (49); -3.4 5/19 (53)
1991	4/22	-4.9 5/01 (2)*
1992	4/01	-12.2 4/7 (5)*; -6.3 4/24 (13); -3.2 4/25 (16); -3.9 5/02 (38); -5.3 5/12 (80)
1993	5/03	None
1994	4/18	-7.2 4/29 (16)*; -3.4 4/30 (17)

[1]Date of third consecutive day where mean daily temperature exceeds 5°C
*More than one day with minimum temperature below -3°C with same number of accumulated degree-days. Only the lowest temperature is shown.

Table 22. Temperatures, dates and accumulated heating degree-days for days where minimum daily temperatures are below -3°C for Cairn Creek study area, Idaho.

Year	Date Dormancy Breaks[1]	Minimum Daily Temperatures below -3°C, Date and (Accumulated Degree-days)
1986	3/28	-3.9 3/31 (10)*; -4.4 4/11 (30)*; -5.0 4/30 (60)*
1987	2/07	-11.1 2/26 (8)*; -11.8 3/28 (17)*; -3.1 4/11 (44); -3.9 4/19 (55)*
1988	2/26	-7.6 3/11 (15)*; -9.3 3/28 (21)*; -6.5 4/05 (22)*; -5.7 4/08 (23)*; -4.3 4/25 (91)*; -3.7 5/01 (102)
1989	3/12	-6.1 4/01 (0)*; -4.2 4/09 (3)
1990	3/31	-5.6 4/29 (74)*

[1]Date of third consecutive day where mean daily temperature exceeds 5°C
*More than one day with minimum temperature below -3°C with same number of accumulated degree-days. Only the lowest temperature is shown.

Table 23. Temperatures, dates and accumulated heating degree-days for days where minimum daily temperatures are below -3°C for Ericson Ridge study area, Idaho.

Year	Date Dormancy Breaks[1]	Minimum Daily Temperatures below -3°C, Date and (Accumulated Degree-days)
1985	4/03	-3.3 4/07 (1); -8.3 4/21 (51)*; -6.4 5/12 (107)*; -3.9 5/13 (109)
1986	3/01	-3.3 3/03 (1); -6.1 3/15 (2)*; -5.6 3/31 (14)*; -5.6 4/14 (23)*; -3.4 4/19 (24); -7.8 4/30 (39)*; -3.6 5/16 (57); -3.2 5/23 (90)
1987	4/02	-5.6 4/13 (13)*; -7.3 4/20 (25)*
1988	2/27	-11.2 3/16 (4)*; -4.6 3/24 (8)*; -8.4 3/31 (9)*; -9.1 4/05 (10)*; -8.8 4/09 (14)*; -4.2 4/26 (69)*; -3.5 5/02 (81)*
1989	4/07	-3.5 4/09 (0); -3.2 5/12 (105)
1990	4/02	-3.3 4/09 (12); -6.4 4/29 (64)*; -3.9 5/08 (85)
1991	4/22	None
1992	2/29	-5.5 3/09 (1)*; -4.6 3/21 (12)*; -3.4 3/29 (13); -8.5 4/07 (30)*; -3.2 4/23 (48); -4.1 4/24 (49); -4.0 5/12 (146)
1993	5/03	None
1994	3/03	-10.2 3/07 (0)*; -10.2 3/24 (6)*; -4.2 4/08 (10)*; -3.9 4/15 (11); -4.3 4/28 (58)*

[1]Date of third consecutive day where mean daily temperature exceeds 5°C
*More than one day with minimum temperature below -3°C with same number of accumulated degree-days. Only the lowest temperature is shown.

Table 24. Temperatures, dates and accumulated heating degree-days for days where minimum daily temperatures are below -3°C for Meadow Creek study area, Idaho.

Year	Date Dormancy Breaks[1]	Minimum Daily Temperatures below -3°C, Date and (Accumulated Degree-days)
1985	4/03	-5.0 4/07 (3)*; -3.3 4/09 (11); -4.4 4/25 (55)*; -3.3 5/09 (116); -5.0 5/12 (120); -4.4 5/13 (122)
1986	3/29	-3.9 4/03 (4); -7.5 4/13 (25)*; -3.7 4/30 (46)*
1987	4/03	-3.9 4/20 (26)*
1988	3/21	-6.7 3/28 (0)*; -3.9 4/08 (7)*; -4.4 4/10 (9); -3.2 4/25 (94)
1989	4/12	None

[1]Date of third consecutive day where mean daily temperature exceeds 5°C
*More than one day with minimum temperature below -3°C with same number of accumulated degree-days. Only the lowest temperature is shown.

Table 25. Temperatures, dates, and accumulated heating degree-days for days where minimum daily temperatures are below -3°C for Peter Ready Creek study area, Idaho.

Year	Date Dormancy Breaks[1]	Minimum Daily Temperatures below -3°C, Date and (Accumulated Degree-days)
1985	4/02	-3.9 4/06 (7); -3.3 4/07 (8); -6.7 4/26 (68)*
1986	2/26	-3.9 2/27 (0); -3.3 3/03 (1); -3.3 3/05 (2); -6.1 3/15 (5)*; -3.9 3/22 (8)*; -3.9 4/03 (31)*; -6.1 4/14 (36)*; -3.3 4/19 (37); -7.2 4/30 (51)*; -4.8 5/11 (61)*; -3.6 5/22 (90)*
1987	2/08	-14.9 3/29 (4)*; -6.4 4/12 (19)*; -6.9 4/20 (32)*; -3.2 5/19 (241)
1988	2/27	-10.0 3/16 (3)*; -9.8 3/31 (8)*; -8.5 4/05 (9)*; -8.6 4/09 (10)*; -6.1 4/25 (63)*; -7.2 5/02 (70)*
1989	3/11	-10.6 3/30 (1)*; -3.3 4/09 (7); -3.7 5/18 (109)*

[1]Date of third consecutive day where mean daily temperature exceeds 5°C.
*More than one day with minimum temperature below -3°C with same number of accumulated degree-days. Only the lowest temperature is shown.

Table 26. Temperatures, dates and accumulated heating degree-days for days where minimum daily temperatures are below -3°C for Twin Creeks study area, Idaho.

Year	Date Dormancy Breaks[1]	Minimum Daily Temperatures below -3°C, Date and (Accumulated Degree-days)
1985	4/07	-3.3 5/12 (105)
1986	3/29	-3.6 4/30 (46)
1987	4/02	None
1988	3/01	-5.6 3/12 (0)*; -4.6 4/09 (10)*; -3.6 4/25 (98)
1989	4/08	-3.4 4/09 (0)

[1]Date of third consecutive day where mean daily temperature exceeds 5°C
*More than one day with minimum temperature below -3°C with same number of accumulated degree-days. Only the lowest temperature is shown.

Table 27. Temperatures, dates and accumulated heating degree-days for days where minimum daily temperatures are below -3°C for Standard Creek study area, Montana.

Year	Date Dormancy Breaks[1]	Minimum Daily Temperatures below -3°C, Date and (Accumulated Degree-days)
1985	4/03	-5.0 4/04 (0); -5.6 4/07 (1)*; -3.3 4/09 (6); -4.4 4/10 (10); -6.1 4/25 (43)*
1986	3/29	-4.4 3/31 (0); -3.3 4/04 (1); -5.6 4/13 (21)*; -6.7 4/24 (34)*; -3.9 5/01 (37); -3.3 5/06 (57); -4.4 5/16 (66); -4.2 5/23 (97)
1987	4/02	-3.6 4/03 (3); -5.4 4/13 (8)*; -5.4 4/20 (17)*; -3.6 4/26 (47)
1988	4/12	-3.6 4/19 (39); -6.8 4/25 (47)*; -5.4 4/27 (48); -3.9 5/02 (54)*
1989	4/14	-3.6 4/18 (10); -4.4 4/29 (30); -3.4 5/12 (87)

[1]Date of third consecutive day where mean daily temperature exceeds 5°C.
*More than one day with minimum temperature below -3°C with same number of accumulated degree-days. Only the lowest temperature is shown.

Table 28. Temperatures, dates and accumulated heating degree-days for days where minimum temperatures are below -3°C for Twelvemile Creek study area, Montana.

Year	Date Dormancy Breaks[1]	Minimum Daily Temperatures below -3°C, Date and (Accumulated Degree-days)
1985	4/10	-6.1 4/25 (23)*; -5.6 5/12 (69); -4.4 5/13 (70)
1986	4/09	-7.2 4/14 (0)*; -8.6 4/30 (6)*; -3.5 5/01 (7); -4.7 5/16 (11)*; -4.8 5/23 (30)
1987	4/05	-7.2 4/13 (0)*; -5.9 4/20 (3); -3.7 5/19 (162)
1988	4/13	-6.6 4/25 (11)*; -5.5 5/01 (15)*
1989	4/14	-4.0 4/18 (2); -4.2 4/29 (10); -3.7 5/12 (40); -3.7 5/20 (55)
1990	4/02	-3.7 4/05 (1)*; -3.3 4/11 (3); -5.2 4/28 (12); -8.8 4/29 (12)*; -3.7 5/08 (23)*
1991	4/21	-4.3 4/26 (10)*
1992	3/14	-7.2 3/21 (1)*; -4.4 3/31 (2); -8.9 4/08 (12)*; -3.3 4/15 (19); -3.3 4/19 (31); -6.7 4/24 (36)*; -5.6 4/25 (37); -4.4 5/02 (64); -5.0 5/12 (114); -4.4 5/13 (114); -3.9 5/16 (122)
1993	5/11	None
1994	4/17	-5.7 4/29 (16)*

[1]Date of third consecutive day where mean daily temperature exceeds 5°C.
*More than one day with minimum temperature below -3°C with same number of accumulated degree-days. Only the lowest temperature is shown.

Table 29. Temperatures, dates and accumulated heating degree-days for days where minimum daily temperatures are below -3°C for Catherine Summit study area, Oregon.

Year	Date Dormancy Breaks[1]	Minimum Daily Temperatures below -3°C, Date and (Accumulated Degree-days)
1988	2/28	-8.6 3/11 (2)*; -5.9 3/30 (10)*; -3.6 4/04 (14); -6.7 4/08 (19)*; -3.2 5/01 (94)
1989	4/07	-4.3 6/16 (361); -4.7 6/20 (379); -4.7 7/17 (672)
1990	3/19	-5.7 3/25 (2)*; -3.8 4/09 (44); -3.6 4/28 (124)
1991	4/21	None

[1]Date of third consecutive day where mean daily temperature exceeds 5°C.
*More than one day with minimum temperature below -3°C with same number of accumulated degree-days. Only the lowest temperature is shown.

Table 30. Temperatures, dates and accumulated heating degree-days for days where minimum daily temperatures are below -3°C for Crystal Springs study area, Oregon.

Year	Date Dormancy Breaks[1]	Minimum Daily Temperatures below -3°C, Date and (Accumulated Degree-days)
1987	3/04	-8.9 3/23 (2)*; -4-4 3/31 (4); -3.9 4/04 (18); -5.0 4/05 (19); -4.4 4/08 (22); -3.8 4/09 (23); -4.4 4/11 (24)*; -7.8 4/18 (41)*; -5.6 4/21 (45); -7.2 5/19 (221)*; -3.2 5/22 (224); -4.1 6/01 (247)
1988	2/27	-4.4 2/29 (1)*; -11.1 3/11 (3)*; -4.4 3/18 (4); -4.4 3/20 (5)*; -10.0 3/29 (7)*; -6.7 4/03 (18)*; -10.8 4/08 (23)*; -8.7 4/09 (24); -4.0 4/25 (67)*; -6.1 4/30 (77)*; -4.3 5/06 (79); -5.2 5/17 (130); -4.3 5/19 (134); -4.2 5/30 (184); -3.3 6/08 (202); -4.4 7/06 (432)
1989	3/11	-8.7 3/14 (0)*; -7.6 3/23 (1)*; -6.3 3/26 (2)*; -4.3 4/11 (21); -4.1 4/12 (24); -4.7 4/23 (71)*; -3.3 4/29 (73); -5.8 5/12 (126)*; -4.5 5/18 (138); -6.9 5/19 (138); -4.6 5/20 (140); -6.3 5/28 (147)*; -3.4 6/10 (232)
1990	3/19	-3.4 3/20 (0); -4.6 3/21 (1); -8.2 3.25 (2)*; -3.2 3/31 (5); -3.2 4/03 (16); -4.4 4/04 (18); -3.3 4/05 (20); -8.5 4/09 (27)*; -3.2 4/10 (31); -3.6 4/12 (34); -4.2 4/26 (78)*; -4.8 5/01 (79); -8.2 5/08 (104)*; -5.6 5/09 (106); -3.3 5/10 (107)*; -4.1 5/15 (108); -4.4 5/16 (111); -3.9 5/17 (112); -4.6 5/25 (123)
1991	4/23	-6.5 5/03 (0)*; -3.6 5/09 (9); -3.5 5/22 (26); -3.3 5/23 (29); -4.3 5/25 (31)*; -3.9 5/27 (32); -4.4 5/31 (35); -4.3 6/04 (48); -3.9 6/14 (84); -4.8 6/17 (92)

[1]Date of third consecutive day where mean daily temperature exceeds 5°C.
*More than one day with minimum temperature below -3°C with same number of accumulated degree-days. Only the lowest temperature is shown.

Table 31. Temperatures, dates and accumulated heating degree-days for days where minimum daily temperatures are below -3°C for Sleeping Beauty study area, Washington.

Year	Date Dormancy Breaks[1]	Minimum Daily Temperatures below -3°C, Date and (Accumulated Degree-days)
1987	4/02	-5.3 4/20 (24); -4.2 4/25 (49); -3.4 4/26 (55); -4.8 5/20 (227)
1988	2/21	-9.6 2/24 (0)*; -4.5 2/26 (1); -4.5 2/27 (2); -4.0 2/28 (4); -8.2 3/17 (10)*; -6.6 3/18 (11); -3.2 3/19 (13); -7.4 3/28 (15)*; -5.6 4/09 (20)*; -4.2 4/10 (24); -5.1 4/26 (81); -5.4 5/04 (92); -3.7 5/07 (98)
1989	4/07	-3.1 4/08 (2); -4.7 4/23 (59)
1990	3/19	-6.7 3/26 (1)*; -4.7 3/27 (3); -3.9 3/28 (5); -3.2 3/29 (7); -3.9 4/03 (27); -3.8 4/04 (31); -3.9 4/07 (44); -4.3 4/09 (45) -3.7 4/10 (48); -3.7 4/30 (105); -5.4 5/08 (147); -4.4 5/09 (150)

[1]Date of third consecutive day where mean daily temperature exceeds 5°C.
*More than one day with minimum temperature below -3°C with same number of accumulated degree-days. Only the lowest temperature is shown.

Table 32. Relationship between phenological stage, minimum daily temperatures, and cone damage.

Accumulated Degree-days above 5°C[1]	Daily Minimum Temperature that will Cause Major Damage	Phenological Stage
0	none	In dormancy
0-10	none	Emerging from dormancy
11-215	-4°C	From pollen cone and seed cone bud-burst through bark slip, leaf bud-burst, shoots start through end of pollen dispersal
over 215	none	During later period of shoot growth and cone production

[1]After three consecutive days of above 5°C mean daily temperatures.

Table 33. Probability of temperatures limiting cone survival and estimated actual cones produced.

Study Site	Year	Lowest Temperature[1]	Should Mature Cones be Produced?[2]	Estimated Actual Mature Cones Produced[3]	Comments
Beacon Light, Idaho	1985	-6.1	No	Few	
	1986	-5.6	No	None	
	1987	-4.0	Few	Yes	
	1988	-4.1	Few	Very few	
	1989	none	Yes	Yes	
	1990	-5.7	No	None	Low Potential
	1991	-8.8	No	Yes	
	1992	-7.1	No	None	Low Potential
	1993	none	Yes	Yes	
	1994	none	Yes	Yes	Low Potential
Brush Meadow, Idaho	1985	-6.1	No	None	
	1986	-4.7	No	None	
	1987	-5.9	No	Few	Low Potential
	1988	-7.3	No	None	
	1989	none	Yes	Yes	
Brushy Fork, Idaho	1986	-6.7	No	None	Low Potential
	1987	-3.9	Few	Few	
	1988	-6.1	No	Very few	
	1989	-6.3	No	None	
	1990	-5.9	No	None	
	1991	none	Yes	Yes	
	1992	-6.3	No	Very few	Low Potential
	1993	none	Yes	Yes	
	1994	-7.2	No	None	1 potential matured
Cairn Creek, Idaho	1986	-5.0	No	None	
	1987	-11.8	No	Few	Low Potential
	1988	-9.3	No	None	
	1989	none	Yes	Yes	
	1990	-5.6	No	None	
Ericson Ridge, Idaho	1985	-8.3	No	None	
	1986	-5.6	No	None	
	1987	-7.3	No	Yes	Low potential
	1988	-8.8	No	None	2 matured
	1989	none	Yes	None	
	1990	-6.4	No	None	
	1991	none	Yes	Yes	
	1992	-8.5	No	None	No Potential
	1993	none	Yes	Yes	
	1994	-4.3	Few	Few	Low Potential
Meadow Creek, Idaho	1985	-5.0	No	Few	
	1986	-7.5	No	None	2 matured
	1987	-3.9	Few	Yes	
	1988	-3.2	Yes	Yes	
	1989	none	Yes	Few	
Peter Ready Creek, Idaho	1985	-6.7	No	None	
	1986	-7.2	No	None	
	1987	-6.9	No	Few	
	1988	-7.2	No	Very few	
	1989	-3.7	Few	None	
Twin Creeks, Idaho	1985	-3.3	Yes	None	
	1986	-3.6	Few	Few	Low Potential
	1987	none	Yes	Yes	
	1988	-3.6	Few	Few	
	1989	none	Yes	Few	
Standard Creek, Montana	1985	-6.1	No	None	4 matured
	1986	-6.7	No	None	Low Potential
	1987	-5.4	No	Few	Low Potential
	1988	-6.8	No	Few	11 matured
	1989	-4.4	Few	Yes	

Study Site	Year	Lowest Temperature[1]	Should Mature Cones be Produced?[2]	Estimated Actual Mature Cones Produced[3]	Comments
Twelvemile Creek, Montana	1985	-6.1	No	Few	
	1986	-4.8	No	None	
	1987	-3.7	Few	Yes	
	1988	-6.6	No	None	
	1989	-3.7	Few	Yes	
	1990	-8.8	No	None	
	1991	none	Yes	Yes	
	1992	-6.7	No	Few	Low Potential
	1993	none	Yes	Yes	
	1994	-5.7	No	None	Low Potential
Catherine Summit, Oregon	1988	-6.7	No	None	
	1989	none	Yes	Yes	
	1990	-3.8	Few	None	
	1991	none	Yes	Yes	
Crystal Springs, Oregon	1987	-7.8	No	Yes	
	1988	-10.8	No	Few	
	1989	-6.9	No	Few	
	1990	-8.5	No	None	
	1991	-4.8	No	Yes	
Sleeping Beauty, Washington	1987	-5.3	No	Yes	
	1988	-7.4	No	Few	
	1989	-4.7	No	Yes	
	1990	-5.4	No	Yes	

Summary:
None expected - none produced; 29 or 35.4%
None expected - few produced; 15 or 18.3%
None expected - many produced; 7 or 8.6%
Many expected - many produced; 15 or 18.3%
Many expected - few produced; 2 or 2.4%
Many expected - none produced; 2 or 2.4%
Few expected - none produced; 2 or 2.4%
Few expected - few produced; 5 or 6.1%
Few expected - many produced; 5 or 6.1%

Number correct; 49 or 59.7%
Number partially correct; 24 or 29.3%
Number in error; 9 or 11.0%
Number Cases 82

---

[1]Lowest daily minimum temperature colder than -3°C between 11 and 215 accumulated degree-days for 5°C threshold
[2]Based on temperature thresholds limits from table 32 and actual temperatures from tables 19 through 31
[3]Based on data from Table 17

CONCLUSIONS

This study shows that temperatures can be used to estimate the effects on western larch cone maturity. Daily maximum and minimum temperatures can be used to compare temperature thresholds with phenological stages. Western larch appears to be slightly more sensitive to temperatures during bark slip, bud burst and shoot elongation.

Existing temperature records from NWS climatological stations or NRCS SNOTEL sites can be used to estimate potential production of mature cones for western larch stands throughout their natural range. If available temperatures are recorded only to the nearest °C, then the threshold for damage would be -4°C for all phenological stages from the time near bark slip up through about mid-point of pollen production.

Temperatures and soil moisture during the previous fall may also correlate with the size of the potential cone crop in the spring, but this theory was not addressed in this study.

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